NOTES

ON THE

GEOLOGICAL SECTION

OF MICHIGAN

FOR

GEOLOGISTS, TEACHERS AND DRILLERS

BY

A. C. LANE AND A. E. SEAMAN

Y THE BOARD OF GEOLOGICAL SURVEY AS
OF THE ANNUAL REPORT FOR 1908

LANSING, MICHIGAN
WYNKOOP HALLENBECK CRAWFORD CO., STATE PRINTERS
1909

REPORT

OF THE

STATE BOARD OF GEOLOGICAL SURVEY

OF MICHIGAN

FOR THE YEAR 1908

GEOLOGY

ALFRED C. LANE
STATE GEOLOGIST

BY AUTHORITY

LANSING, MICHIGAN
WYNKOOP HALLENBECK CRAWFORD CO., STATE PRINTERS
1909

MAY 18, 1910

BOARD OF GEOLOGICAL SURVEY

1908

EX OFFICIO:

THE GOVERNOR OF THE STATE,

HON. F. M. WARNER, *President.*

THE SUPERINTENDENT OF PUBLIC INSTRUCTION,

HON. L. L. WRIGHT, *Secretary.*

THE PRESIDENT OF THE STATE BOARD OF EDUCATION,

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Botanists.—Prof. W. J. Beal, Agricultural College; Prof. F. C. Newcombe, Ann Arbor.

Zoologists.—Prof. W. B. Barrows, Agricultural College; Prof. J. Reighard, Ann Arbor.

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LANSING

ALFRED C. LANE, State Geologist.

W. F. COOPER, Assistant.

H. R. WIGHT, Clerk.

HOUGHTON

A. H. MEUCHE, Engineer in Charge.

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TENTH ANNUAL REPORT

OF THE

STATE GEOLOGIST

ALFRED C. LANE

TO THE

BOARD OF GEOLOGICAL SURVEY

FOR THE YEAR 1908

BY AUTHORITY

LANSING, MICHIGAN
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REPORT.

To the Honorable the Board of Geological Survey of the State of Michigan:

Gov. Fred M. Warner President.
Hon. D. M. Ferry Jr., Vice-President.
Hon. L. L. Wright, Secretary.

Gentlemen:—I beg to present herewith this my tenth report for the fiscal year from July 1, 1907, to June 30, 1908, inclusive, and for the field season of 1908.

FINANCES.

The following is the usual statement of expenditures from the annual appropriation:

	Salary.	Field.	Office.	Total.
July	$566.50	$106.28	$28.49	$701.57
August	673.47	395.78	58.19	1,127.44
September	453.00	125.25	48.61	626.86
October	659.26	468.09	18.30	1,145.65
November	399.21	50.14	47.94	497.29
December	460.73	4.82	33.29	498.84
January	427.90	8.38	63.16	499.44
February	599.40	6.51	85.59	691.20
March	410.30	1.45	59.93	471.68
April	510.70	......	50.80	561.50
May	410.40	4.48	24.95	439.83
June	654 80	27.77	56.43	739.00
Total	$6,225.67	$1,198.95	$575.38	$8,000.00

In addition to this we had:
For year 1907-8, $3,000.00. Bal. remaining Nov. 1, 1908, $0.01.
For year 1908-9, $1,000.00. Bal. remaining Nov. 1, 1909, $224.93.

With this the Milford and Howell quadrangles have been completed and the Mason quadrangle begun, bringing the survey up to the Agricultural College. The Calumet Special has been continued, but practically without special aid from the fund for joint topographic survey, but rather in appreciation of the international importance of McNair's and Hayford's work on gravity.

Owing to the United States and State using different salary tables for fractional parts of a month (producing friction out of all proportion to the few cents involved) the two statements are not precisely the same.

The $1,000.00 for the biological survey has been expended under the charge of A. G. Ruthven, Chief Field Naturalist of your Board, mainly in Huron county.

Balance remaining Nov. 1, 1908, $214.66.

On Nov. 1st there remained in the current appropriation for 1908-9, $4,666.85.

PUBLICATIONS.

At present practically the sole official publication of the Board is its annual report.

The report for 1907, the text of which is all printed, contains:

My executive report with notes on peat, coal, lime and cement.

A report on molding sands by Ries and Rosen.

A popular account of the surface geology of the state as a whole, with (as Plate XII of the same) a map covering the Lower Peninsula. This plate was authorized by the State Board of Auditors only on November 25th.

A report on the geology and biology of Walnut Lake, a lake accessible to a large population and an attractive spot for nature study. Its study has also furnished a clew to the distribution of whitefish in our smaller lakes.

A special edition of maps of the surface geology of the Lower Peninsula has been asked for by the Agricultural College people and a map of the Ontonagon county mining district (the region of the Mass, Adventure, Michigan, Lake and other properties) was of current interest. But owing presumably to the condition of the state treasury, the Board of Auditors did not see fit to authorize them. With your consent the use of this latter map for reproduction was offered to the public press and through the Hancock Evening Copper Journal the firm of Gay & Sturgis issued an edition of the same. The conditions were that the edition was for *gratuitous distribution* and that a part of the same was furnished our office without the advertising matter which they naturally ran to pay the expense. The distribution was certainly more effective than a state publication could have been, and saved our office much time and postage. No criticism has been received and it seems better that our work should be promptly published thus than be prolonged until out of date, even though the form of publication is hardly dignified.

Other publications regarding or including our work are as follows:

A. C. Lane:

Statement to Citizens' Committee regarding Saginaw water supply;[1] statement regarding the results of molding sand work of Rosen;[2] letter on mine waters;[3] notes on Ann Arbor Folio;[4] genetic connection of certain granitic dikes;[5] the ophitic texture;[5] mine waters (which contains a large number of analyses[6] by various authors):

[1]Pp. 27-28 of their Proceedings, and Saginaw daily papers, Jan. 16-19, 1908.
[2]Lansing Journal, Jan. 23, 1908, and other papers.
[3]Calumet News, April 18, 1908, and other Houghton and Keweenaw county papers.
[4]Michigan Miner, May, 1908.
[5]Bull. Geol. Soc. of America, 1908, pp. 644-648.
[6]Proceedings Lake Superior Mining Institute, Vol. XIII, pp. 63-152.

W. F. Cooper: Michigan Topographic Surveys,[1] Pleistocene Beaches of Saginaw county,[2] the Saginaw-Grand Ship Canal.[3]

A. W. Grabau and others (W. H. Sherzer).

New Upper Siluric Fauna from Southern Michigan with W. H. Sherzer, C. S. Prosser, A. C. Lane.

Nomenclature and Subdivision of the Upper Siluric strata of Michigan, Ohio and Western New York.[4]

WORK READY FOR PUBLICATION.

There have been handed in, ready with a little revision, for the report of the Board for 1908:

A report on Mt. Bohemia, by F. E. Wright.

A report on the Development of Mining Machinery and the Geological Factors Therein, A. H. Meuche.

A report on the Ecology of Isle Royale, by Chas. C. Adams.

A report on the Algonquin Beaches of Lake Huron, by W. M. Gregory.

A report on the Monroe Group in Southern Michigan, the group of the strata traversed by the new salt shaft, by W. H. Sherzer and A. W. Grabau, may perhaps be included.

While a large mass of data regarding the copper-bearing rocks has been accumulated, publication in official channels seems to meet the needs of those interested and the size and expense of the annual reports seems to be now more than the Board of State Auditors will stand!

With modern methods of typesetting and preparing copy, the compositor is getting to be a part of a mere machine for turning typewritten copy into leaden slugs. The old fashioned compositors and proof-readers who knew more of composition and spelling than most authors are becoming extinct. The demand is becoming more and more insistent that the typewritten copy shall be letter perfect. Again, the demand of engineers for large scale maps can be as cheaply met for small editions of 500 or so by blue prints or brown prints from Van Dyke negatives.

Finally the ease with which photographs can nowadays be taken, and the widespread familiarity with the simple technique required, favors the transmission with each report of a lot of photographs. These are not all first-class photographs, nor such as reproduced by the half tone process will explain much or add materially to conclusions of the report. In many cases pen and ink sketches would really illustrate better. Yet they are not without value as unimpeachable witnesses to the conditions and facts mentioned in the report. It is important that the original data upon which a scientific investigation is based should be accessible and on file for certain specialists. But the circle of these is limited compared with those who are interested in and can understand only the conclusions.

It is a question whether the time is not at hand when authors can give their reports a winnowing process before publication whereby the complete report with all data shall be typewritten in as many copies as convenient, with all the photographs and prints of the illustrations

[1]Michigan Engineer for 1907.
[2]Tenth report Michigan Academy of Science.
[3]Michigan Miner, November, 1908.
[4]Bull. Geol. Soc. Am. (1908), pp. 540-556.

full size, while only certain chapters embodying the conclusions, the data of wide interest, and a selection of the illustrations, and maps on a relatively small scale are published, *with a reference to the fact that fuller data may be obtained by those interested.*

CO-OPERATION.

We have continued the policy of co-operation with the agencies and individuals studying the natural resources of the state listed in my last report. And in addition the new work of the Board of Health, that of water testing under State bacteriologist Dr. M. L. Holm, has been a great help to us. The laboratory office is on the same floor as that of mine in Lansing. He has made at our request a number of tests of waters which are or might be used for water supply, the results of which are of use to us, and for which our thanks are due to him and to Dr. F. W. Shumway, Secretary of the Board.

In one case a geological fault in the strata seems to be indicated by the character of the waters on the two sides.

It is also true that a number of things more or less depended upon by chemists as guides to the safety of the waters such as chlorine, nitrates, nitrites, ammonia, etc., can only be thus used with due regard to the geological conditions, and this is especially true in Michigan. Dr. Holm feels this quite strongly. Thus our intercourse has been of mutual help, and such water testing work should only be done in close co-operation with competent geological advice.

WATER.

We agree that unfiltered surface water is *not* a desirable city supply. Under that head we also include waters of the Great Lakes.

In comparing surface water and artesian water the fact that the latter is usually harder and causes the use of more boiler compound and soap or separate soft water systems, should by no means be forgotten. The saving of the hard water which may readily amount to a cent a thousand gallons for large and important uses, may pay for the cost of adequate filtration of soft water. At any rate it will go a long way toward it. *One important exception to the harder character of artesian water is the relatively soft water that can be obtained from the Potsdam (Lake Superior) sandstone*, by the towns along Green Bay[1], which have thus no excuse for their high typhoid rate.

WORK OF THE YEAR.

The State Geologist has several times been called upon for advice regarding water works, and has made one special trip to Saginaw. Without usurping the field of the Board of Health or the hydraulic engineer, we have tried to give that class of help for which we may naturally be asked.

Most of his time has been spent in examining specimens sent in and reporting their nature. The bulk of these have been samples from wells and from drill cores in the copper country. A fund of geological information not otherwise to be obtained has been gathered, and while im-

[1]See report for 1903.

mediate needs are answered by private correspondence, special conclusions from these larger pieces of work should find their place in special reports.

There was a meeting of State Geologists at Washington, D. C., last spring at which an association was organized and important steps taken to promote harmony in names. The visit of the Geological Society to Albuquerque gave opportunity to collect some desert sands to compare with the Sylvania sandstone. The visit of the Lake Superior Mining Institute to Minnesota gave an opportunity to study some rocks and cores which have parallels in Michigan. On the way back a stop to visit the Wisconsin-Michigan boundary line (Fig. 3.) yielded results of so much interest in connection with the question of the relation of the copper bearing rocks to the Lake Superior sandstone that the place was revisited later with Leith and Martin of Wisconsin University. These trips were not at the expense of the state.

A two days visit at the suggestion of Hon. Geo. Shiras, III, was made to a salt lick not far from Marquette, of interest both from a geological and biological point of view. (Fig. 1.)

Studies of the salt in mine waters have been presented to the Lake Superior Mining Institute, and reprints of this obtained which may serve until the state is ready to issue a larger report with data collected to date.

Visits were made and field work done in connection with the party of A. H. Meuche beyond the Victoria, and F. E. Wright in the Porcupines. In view of the probable use of the same at once a preliminary map is submitted herewith. (Plate I.)

Dr. F. E. Wright has spent the season in the Porcupine Mountains finishing the field work for his report. In this he received technical assistance from E. S. Larsen, Jr., and the State Geologist. L. Squance was also employed. With the State Geologist a brief trip was made to the Lake Gogebic region north of Berglund where as Wadsworth noted these are interesting porphyry intrusives.

A. H. Meuche has had charge of the Houghton office, and of a party in the field continuing the examination of the Copper Range from the Victoria mine on. He prepared the map of the Ontonagon county mines published, and has assisted in the examination of drill cores, and has made important correlations of the Ontonagon county lodes.

Karl and Leon Meuche and Harold E. Mitchell, and for a short time Dr. R. E. Hore, assisted A. H. Meuche.

Analyses have been made by Dr. A. A. Koch, of the College of Mines.

The topographic survey was in charge of the U. S. Geological Survey, around Calumet, under A. M. Walker, and around Howell and Milford A. M. Walker and C. D. S. Clarkson. With them were employed J. DePuy, Leigh D. Townsend, C. B. Kendall, R. H. Wilson, S. R. Archer, R. C. Gaylord, J. W. Matthewson, S. L. Fuller, Perry K. Miller and Frank A. West.

Harry R. Wight has had charge of the correspondence, and in fact of the whole Lansing office, during the extensive absence of the State Geologist in the Upper Peninsula and elsewhere, and has assisted in editorial work, preparation of Mss., blue printing, etc.

W. F. Cooper had practically almost complete editorial charge of the report for 1907, and has also continued work on Saginaw county.

Of those employed a part of the time or on contract, the following report may be made:

Profs. W. H. Sherzer and A. W. Grabau have studied the salt shaft section and the adjacent outcrops.

Prof. C. A. Davis has been engaged by the U. S. G. S. as peat expert, but has practically finished his Tuscola county report.

RECOMMENDATIONS REGARDING LEGISLATION.

The consideration of natural resources is of ever increasing importance and of even wider popular interest, as emphasized by the White House conference this year, to which a number of State Geologists, and the President of this Board were delegates. It occurred practically at the same time as the meeting of the Association of State Geologists above mentioned.

This is the field of your Board and your increasing work should receive adequate consideration by the legislature. The reports for 1906 and 1907 have already fully set forth our needs for a new building, especially for the care of drill cores. These have cost $5.00 a foot for private parties to obtain, and are of permanent geologic value. Such a building (which should even then be built with an eye to future enlargement) might easily cost $30,000.00.

The topographic survey has now reached the Agricultural College and should certainly be extended to include the neighborhood of the State Capitol. For this $5,000.00 will be sufficient. If, however, the region of the Kalamazoo or Mt. Pleasant Normal is to be covered, and more especially if the region between Grand Rapids and Saginaw, where the deep waterway is proposed, is surveyed, and this is the first step towards an adequate detailed estimate on the project, six thirty-minute quadrangles, say 6,000 square miles, should be surveyed. Taking fifteen-minute quadrangles, however, the area might be reduced to 3,000 square miles, and the state's half of the cost to about $33,000, to be met by an equal sum by the Federal government. But inasmuch as the U. S. Geological Survey has only been having about $100,000 available for such joint topographic surveys, and adjacent states like Ohio, Kentucky and Illinois have been calling for $10,000 and $20,000 a year therefrom, it is quite doubtful if they can at once meet such an appropriation unless the Federal appropriation for such purposes is also raised. Thus whatever is given should be given as a lump sum, available until exhausted as fast as it is met by the general government.

The work of the biological survey is fruitful and should be continued with an appropriation of about $2,000. Detailed estimates will be later submitted. The collections acquired are of such a different character from those of the geological survey, that the rules covering their care and distribution should be different. There is no reason at all why they should be a part of the same collection. The Museums of the University and of the Agricultural College should be made the permanent recipients, and if as seems true upon careful reading of the acts legislation is necessary to make this legal, such action should be taken.

The work of the geological survey is such as to bring prominently to view the importance of many of the legislative recommendations of the commission of inquiry on the state tax lands. Most especially is to be recommended the withdrawal of all such lands from sale until their value to the state for the purpose of regulating water power and floods, and the production of oil, gas, coal, etc., shall be adequately investigated. In particular is this advisable until the state has adopted some policy of licensing and control for exploration for gas, such as outlined in my report for 1907.

With an expression of appreciation for the advice of the Board of Scientific Advisers and the faithful work of my fellow employes I would close this executive part of my report and add a few notes on matters of current interest not reserved for inclusion in separate scientific reports.

During the year we have received, as a gift from Mr. and Mrs. Frederick Towle of Detroit, original notes, papers and memoranda of Bela Hubbard, who did a very large part of the Douglass Houghton Survey. These papers contain data of decided historic and scientific interest. The reports of that survey are exceedingly rare and should be reprinted with the help of these original notes. There are also meteorological and anthropological data of value.

BRICK.

While there are large areas of excellent shale for brick in the state,[1] yet the scarcity of lumber is such that all the lumber substitute industries are doing well. The sand-lime brick industry is firmly established. Some hints of value may be given by reprinting with notes, extracts from a very practical address in the Clay Record for April 30, 1907, with running comments as to their applicability in Michigan.

Extracts from an Article on "Proper Mixture and Mixing for Making Sand-Lime Brick[2]," with comments.

"It is said that any sand is suitable providing it consists principally of material containing silicic acid, which is the case almost everywhere, and more especially with bank or river sand and sandstone rock.[3] A large portion of calcareous marl[4] will make the sand useless, as the substance can not participate in the chemical transformation into silicates of lime. On the other hand sand composed of small pieces of limestone[5] has produced a very firm hard brick, when mixed with a small portion of finely ground clay in addition to the hydrated lime, but I do not recommend this sort of mixture, because the brick of such a composition are not as refractory[6] in case of fire in building in which they have been used. * * * *

"We are also told that a small amount of fine loam will be of no disavantage. Again I differ with that theory, because I have seen sands

[1]See previous reports, especially Volume VIII, Part I.
[2]Clay Record, April 30, 1907.
[3]Stamp sand, especially that of amygdaloid mines, is not high in silicic acid and should not be used where exposed to alternate wet and dryness. The sand of the Great Lake shores and the sandstones of the Lake Superior (Munising) and Marshall and Saginaw (Coal Measures) formations are highest in silica, but the dune sands are round and even sized.
[4]Bog lime.
[5]Many of the glacial sands and those along the Niagara and Dundee outcrops are limey. In fact most of the overwash gravel sands are limey until they are leached.
[6]That is they melt readily.

in which the individual grains were coated with a very fine loam or clay dust. This coating prevents the lime from coming in contact with the silica, consequently making an improper bond and a punky brick.

* * * * * * * * * *

"Again, some very good looking and hard brick have been produced from sand and loam mixed, but I would not care to use such brick in a building, as they would disintegrate by frost or fire.[1]

"A high percentage of silica is very necessary, and without it you cannot expect to get good results. Candidly speaking, it is a hard proposition to get perfectly clean sand in the ordinary bank[2] on account of the vegetable matter and the soil on the surface, that caves down as the bank is worked. In such cases it is better to remove all the top of the soil, prior to working the bank.

With river sand you may get a good quality for a short time, and when freshets come and deposit mud and slime on top of your sand, you are really up against a bad proposition. My advice in working river sand is to get it out in large quantities and keep a supply ahead, so that it is unnecessary to go into the river immediately after a freshet for your daily supply.[3]

"Sea sand is being used for brick making, but some have used it to their sorrow.[4] Sea sand that comes in contact with the salt water will not make good bond with the lime; again, this class of sand is of the round grain variety.[5] The only sea sand that is practical to work is that which has been away from the sea water for years, and has been purified by the elements.

* * * * * * * * * *

Another matter of great moment in selecting sand is, to get it of varied sized grains.[6] If it were possible to get proportioned as follows, you need not worry about the results: 20 per cent passing 20 mesh, 20 per cent passing 40 mesh, 20 per cent passing 60 mesh, 20 per cent passing 60 mesh, 20 per cent passing 100 mesh screens, providing it is a clean, sharp sand, and you are using a high calcium lime in your mixture, in proper portion, you will get good results. Where you use a coarse sand of nearly one size grains, you will not be able to make a compact brick, impervious to water.

* * * * * * * * * *

"It has been thoroughly demonstrated that five per cent[7] of calcium hydrate, with a clean sharp silicic oxide, is a sufficient amount to make hydro-calcium silicate or sand lime brick. A proper amount is governed by the quality of the sand and the lime to be mixed, and when the

[1]Loamy or clayey, dirty sand is decidedly unsatisfactory.

[2]That is in high level of old beach or glacial sands. There is also more or less decay of those sands which are not all quartz which tends to weaken the brick.

[3]Little or no present river sand has been worked in Michigan, but the advice to be sure to keep out of the reach of freshets is worth noting.

[4]This does not apply to sand of the Great Lakes.

[5]Much of the lake sand is of this round grain, even sized variety, especially the dune sand. In such case regrinding is a great improvement. This is done at the Manistee plant described by J. J. Hubbell in the Michigan Engineer.

On the other hand, the glacial sands vary much in grain and there are often extremely fine sands. Data as to the proportion of grains of different sizes will be found in the U. S. Department of Agriculture soil reports and in the Ries & Rosen molding sands report (Annual report for 1907.)

The open, very porous sand brick will, however, stand frost better than some would expect but the corners are liable to chip in the handling.

[6]Much of the sand of the glacial over wash is quite varied in size.

[7]Six per cent or so is used in Michigan.

GEOL

T. 51 N.

Preliminary Geological Map of the
PORCUPINE MOUNTAINS AND VICINITY
by F. E. Wright and A. C. Lane.
1909
Including work of field seasons of 1900 1903, 1907, and 1908 and notes of P S Smith, E.W. Wieland, W V. Savicki, A F. Benson, A E. Seaman. and M.E. Wadsworth.
Base of Nonesuch Shale Series.
Black and grey micaceous shales and grits of about 500 to 600 feet thick; at base, a thin stratum of greenish conglomerate containing an occasional red pebble. Overlain by the Freda Sandstone Series.
Base of Lake Shore Trap Series.
Fine grained traps with coarse quartzose amygdaloids from 300 to 500 feet thick, overlain by the Outer Copper Harbor Conglomerate and underlain by a red sandstone broken with epidote and calcite seams.
Chippewa Felsite and Porphyry.
Above the Chippewa Felsite are a few hundred feet of traps, then about 2000 feet of the Great Copper Harbor Conglomerate and Sandstone.
Copper appears to be principally accumulated near the Base of the Nonesuch Shale and the Lake Shore Traps
R. XLIV W.
R. XLIII W.
R. XLII W.
R. XLI W.
R. XL W.
R. XLV W.
T. 51 N.
T. 50 N.
T. 49 N.
T. 48 N.
LAKE SUPERIOR
Elevation 602 ft.
Lone Rock
Lafayette Landing
Carp River
Little Carp River
OLD CUYAHOGA MINE
OLD UNION MINE
OLD HALLOWELL MINE
OLD LAFAYETTE MINE
NONESUCH MINE
PINE MINE
Little Carp L.
Union River
Iron River
Mineral River
Pine River
Duck River
Halfway River
Little Cranberry River
Cranberry River
GREEN
LAKE SHORE TRAP
PORCUPINE MAIN FELSITE
FAULT
BASE OF NONESUCH SHALE
CHIPPEWA FELSITE
MAINLY PORPHYRIES AND FELSITES
COARSE PHYRITES WITH RED INTRUSIVE PORPHYRIES AND FELSITES
BASE OF LAKE SHORE TRAPS
BASE OF CHIPPEWA FELSITE
Clark L.
Bass L.
Ontonagon River
BERGLAND
LAKE GOGEBIC
El. 1289
LAKE GOGEBIC
BALLENTINE P.O.
GROESBECK

mixture is made damp, a chemical combination takes place and forms silicate of lime.

* * * * * * * * * *

"If you use a high calcium lime[1] virtually free from magnesia and a clean sharp silica sand, you have an easier proposition than the fellow who has a magnesium lime and clean sharp sand, because he will get a chalky brick and you can rub the grains of sand from a hardened brick with your thumb and finger.

"Should your lime contain a high percentage of calcium and be practically free from magnesia, your sand round grained, you will not get a good brick, while if you are using a high magnesium lime and a loamy sand, either sharp or round grain, your troubles will be too numerous to mention."

PEAT.

By C. A. Davis.

Thinking to supplement my former report to your honorable Board relative to the peat deposits of Michigan, I take this opportunity to write you briefly concerning the progress of peat investigation, and the industries based upon this, for the year 1908.

The most important, generally applicable announcements have come to us from Europe, as usual, and are two in number: (1). The Ekenberg "wet carbonizing" has been worked out sufficiently to demonstrate that it is a most promising commercial probability. The process, as you may recall, is, as its name indicates, a method of treating wet peat in closed retorts with superheated steam under more than 5 atmospheres (75 lbs.) pressure and at a temperature above 300° F. This carbonizes the peat without volatilization, and, after the process is complete, the water can be nearly all removed by pressure. Drying is completed artifically and the resulting peat substances is easily compressed into very hard, black, non-absorbent, heavy briquettes, which have a high fuel value and are much like coal.

This process has not been tried on actual commercial scale but was very exhaustively tested by the Swedish government, and the experts who made the tests report favorably upon the process and its results. The cost of establishing a plant equipped for this process, with a capacity of 100 tons of briquettes per day, is estimated to be somewhat more than $150,000, exclusive of the cost of the bog, and the cost of production at about $2.25 per ton.

(2.) The Frank Caro method of producing gas from peat with the recovery of ammonium sulphate as a by-product. This is exciting even more interest than (1) since it is in line with the recent advances made in the utilization of other low grade fuels as sources of gas for use in the producer type of internal combustion engines. The peat is dug and partially dried on the bog to about 40 per cent or 50 per cent moisture, and without other treatment is thrown into a gas producer of special construction, where for a considerable time it is heated with a mixture of air and excess of superheated steam. During this treatment practically all of the nitrogen of the peat is converted into ammonia, which is con-

[1]The Fiborn Quarry mine, much of that from Alpena and Petoskey and that from the Bay Port or Mayville limestone, and that from the Sibley quarries is of that nature. Much of the Monroe county lime and that of Manistique and the Niagara formation, and Green Bay generally is likely to be magnesian.

verted to ammonia sulphate by passing the gas through sulphuric acid, and recovered by concentrating the liquid. The pure peat gas, with a heating value of 145 to 155 B. T. U. per cubic foot, which is about that of producer gas from coal, may be used for the production of electric power or for any similar purpose. The important part of the discovery is that the ammonium sulphate recovered from a peat with slightly more than 1.5 per cent combined nitrogen which was used in one large experiment, was sufficient in quantity to pay the entire expense of the process, and give a small profit, leaving the gas which amounted to some 48,000 cubic feet per ton of dry matter of the peat, with 152 B. T. U. per cubic feet, as an additional profit.

As in all plants for gas production on any considerable scale, the cost of this type is large, and is estimated at not less than $150,000. This method of utilizing peat on a large scale is probably the most promising of any of those recently proposed and opens up great possibilities for the utilization of the larger peat beds of Michigan as sources of power to be used in the vicinity of the plant, or transmitted electrically, at a distance.

The fact that several of the analyses of Michigan peat show as high as 2.5 per cent, or more, nitrogen, indicates that aside from the power stored in her bogs, the state has a great amount of combined nitrogen laid down in them, which may be very profitably recovered in the form of ammonia sulphate, and be used in enriching her agricultural lands, since the salt is a very important constituent of high grade fertilizers.

During the past year there has been a rapid improvement in the type and efficiency of gas producers for making producer gas from fuels of the high grade to which peat properly belongs, and it is now possible to buy producers of the suction type which will use moist peat in units as low as 150 horse power. If the improvement continues, as it seems likely to do, it will be only a short time before the producer gas engine, capable of using air dried peat in the form of unshaped masses as dug, will be used in many small factories which are located near peat beds, in place of steam engines now in use.

There has been some activity in the manufacture of peat fuel in the state, although none of the large fuel plants were operated during the year. Mr. Karl Kleinstuck, of Kalamazoo, made something over 100 tons of peat blocks at his Elk Marsh Peat Works, and found ready sale for such of the product as he cared to dispose of, but reserved the greater part of it for his own use.

The plant of the Artificial Fuel Co., of Toledo, Ohio, located near Lambertville, Michigan, was in operation for a short time for the production of material for experimental purposes, but although fully equipped, the company have not tried to operate on a commercial scale until the electric railway crossing their property is completed. The litigation which has prevented this has been settled and the road will be finished early in 1909, after which the peat fuel plant will begin production on full time, if the present plans of the management are carried out.

Peat fuel has been made in some quantity also near Hudson, by the Metropolitan Artificial Fuel Co., of Toledo. The product made by this company was in the form of large blocks, poorly macerated and air dried.

It was bulky and friable, in the samples shown the writer, and apparently little better than cut peat, but considerable of it was sold.

Several new peat companies have been formed in the state, but they have not yet reached the producing stage. Among these may be mentioned the Consumers' Peat Fuel and Gas Co., of Detroit, which will operate in 1909, a plant at Bancroft. The plants at Chelsea, Bancroft and Eaton Rapids were not run during the season of 1908, and nothing was learned of the peat paper plant at Capac.

It is surprising that no attempts have been made in Michigan to make peat or "moss" litter, for use as bedding for horses and other stock. There is an abundance of the fibrous type of peat which is best adapted to this purpose, the processes of preparation are the simplest, and those who have given it a fair trial are enthusiastic as to its many good qualities, so that it would find a ready sale.

From the foregoing it is apparent that the peat question is still a live one, and that the men interested in peat development are still sure of the success they so well merit from their perseverance under many difficulties, and are expecting to establish an important industry and furnish the people of the state a good, efficient, auxiliary fuel at a low price.

The new developments discussed above, while requiring large capital, will in the near future doubtless reach the stages where capital will be available, and Michigan, with its extensive peat beds should be one of the first states to be enriched by plants based upon their exploitation.

SALT LICK.

The carving of wild animals for salt is a notable phenomenon. Thus when Hon. George Shiras, III, called my attention to some remarkable salt licks near his hunting camp, it was a matter I was glad to investigate for the benefit of the biological survey as well as because of the light it might throw on mine waters, oil and gas, and geological theories as to the origin of the deposits in question. This is perhaps the first attention we had paid to natural salt springs since the days of Douglass Houghton, who investigated a number as indications of salt. The licks in question occur at the head of Whitefish Lake. This region has been well described geologically by Rominger[1] but is very imperfectly shown on the maps so that we need to insert the following sketch figure.[1]

This lake is about 3 miles south of the flag station Deerton, on the Duluth, South Shore & Atlantic R. R. If this is as Gannett gives it 716 feet A. T., Whitefish Lake is about 796 feet A. T. It is not far from the Agricultural Experiment Station, Chatham, and is covered but not shown on the Munising soil map of the U. S. Department of Agriculture.

The river (Whitefish or Laughing Whitefish river) which drains the lake, flows over ledges and rapids of sandrock. Not far from the outlet on the east side there is exposed a flat ledge (Snake Rock) of white sandrock, about 100 feet square, just about at water level. The outlet is clogged with large blocks of sandrock.

The figure shows how long and narrow the lake is and it is deep.

[1]Volume I of these reports, Part 3, pp. 74, 75, 88-90.

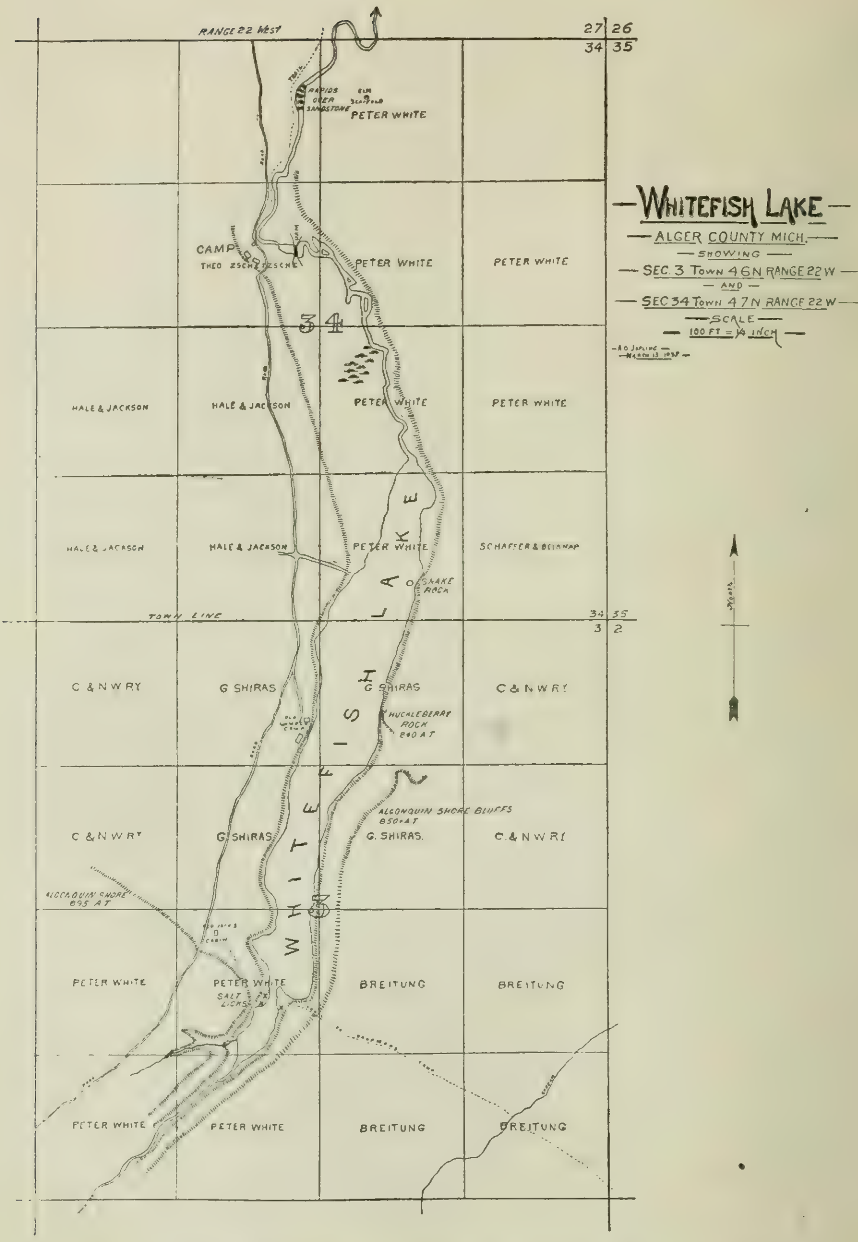


Fig. 1. Sketch Map showing location of Whitefish Lake Salt Licks.

It is said to be not less than 60 feet deep for a good part of the way. At the north end of the lake the level of the country is hardly 10 feet above the lake, but as we go south it rises somewhat, and south from Huckleberry rock the top of the bluffs 840 to 845 feet A. T. is a lake cut bench just below the well marked shore line of a vast lake of which Lake Superior is but a relic—the former Lake Algonquin. Near the head of the lake we find, on each side of this old shore line, back of which the country rises suddenly over greenish white sandrock and blue shale to 95 feet above the lake, or 890 feet A. T. The gorge of the inflowing river, which continues the lake, is thus quite deep, 100 to 150 feet. About four miles south it terminates in a series of falls something like 75 to 100 feet high. The sandstone beds exposed are all in that upper part of the Lake Superior (Potsdam) sandstones, that I propose to call the Munising sandstones. The section as given by Rominger is from above down, as follows;

6.	Massive but soft white sandstone in vertical cliffs..................	50
5.	Thin beds of soft white sandstone parted by seams of blue shale.....	75-100
4.	Thicker ledges with quartz pebbles, a few feet dark coarse conglomerate	
3.	Hard sandstones, coarse red-specked..............................	4-20
2.	Argillaceous red sandstone 1 to 3 feet thick, and red shales..........	12
1.	Thin bedded sandstones and shales, white, or blotched white and red.	25

The bluffs at the head of Whitefish Lake show 5. Down to Huckleberry rock the bluffs appear to be capped by 3 or 4 and underlain by 2. The salty water must come near the line between 2 and 1. The length and narrowness of the lake and its vertical sides suggest at once that it has been formed like the gorge above, by the cutting of a stream. The apparently greater depth than at the outlet (like the gorge of Niagara and the "Dead Sea" in the Adirondacks) may be due to the plunge of an interglacial or preglacial waterfall.

The salt water occurs on both sides of the inlet at the head of the lake, at points about opposite, near where the cover over the sandstone thickens. It probably oozes from a given stratum. Or if it finds its way up by a cross fissure it must have spread through the strata for some distance. Tests under Huckleberry rock and at another point yet nearer but to the north do not show the abnormal chlorine to anything like the same extent. Neither does the river water, the lake water nor wells nor springs in the sides of the bluffs. It is also very interesting, almost surprising, to find that the water is not only saline but contains chlorine so much more than sodium that we are constrained to infer the presence of calcium chloride, the same salt which is found in paleozoic brines very widely and in the mine waters of the Upper Peninsula. It is therefore no indication of the ocean having entered this region during the postglacial depression.

The places frequented by the deer were in the sand flats of the delta of the Whitefish as it comes into the lake (Analyses 7-12). Here along certain fallen trees Mr. Shiras has observed the deer ranged in a row like cattle. Digging directly at the sandstone bluffs near by disclosed the same or stronger waters. The details of the tests follow:

1. Incoming river water (mg. per liter) by silver nitrate tablets has about 12

parts million of chlorine. The carbonates if all calcium, would (by sodium acid sulphate test) be about 50 per million.

2. The hardness of the outflowing water by soap test, if all calcium, would be about 80 per million.

3. A hole dug at the base of the bluffs near Huckleberry rock on the east side of the lake yielding water probably from the rock (temperature 55° F. where the lake was 66°) yielded by silver nitrate test,

Of chlorine	30 parts per million
By soap test, hardness as calcium	49 " " "

4. The shallow (10 foot) well at Shiras' camp has so little chlorine that 250 cc is not enough to neutralize a silver nitrate tablet corresponding to 1.01 mg Cl.:. Cl is 4 parts per million. By sodium acid sulphate test the carbonates as Ca were 32 per million.

5. Water from the sandstone 60 feet above the lake has by sodium sulphate test of carbonate 40 per million.

6. A hole near the head of Buck Bay under the bluffs only a few feet from the licks was clayey and therefore not accurately to be tested, but contained no great amount of chlorine.

7. Sample of lick sent in Nov. 9, 1907, by George J. Shiras, III, tested by F. B. Wilson. Only a few cc of water available gave,

Cl	862 per million.
Total solids	2482
S (SO_3)	27
Mg	tr.
Ca., Na., etc	present but not determined

At the time the sample was taken there was a pink scum on the water, probably organic, like a pink bacterial scum which C. A. Davis tells me he has noted on salt marshes. The lick itself was muddy with slime from the river and the tramping of the deer and full of fallen timbers, but we had dug with pick and shovel two shallow holes not over a foot and a half shoreward from the main lick.

8. The first hole closest to the lick gave Cl. 2370 per million by silver nitrate tablets and, by sodium acid sulphate, carbonates as Ca 100 per million.

9. Another hole not 10 feet off going down into the clear white sand of the decayed sandrock gave Cl. 1750 per million. The temperature was 57°—of the river 63°-65° on Sept. 11, 1908. A sample was taken also for preservation in a jug.

10. Over on the west side of the stream was another lick in a miry spot. This gave:

By silver nitrate test	Cl.	1200 per million
By soap solution, hardness as calcium	Ca.	82
By sodium and acid sulphate, carbonates as calcium	Ca.	235

Phenolphthalein does not indicate any sodium carbonate, nor does acetate of lead show any sulphides. The sandstone outcropped within 10 feet. There is quite liable to be urine contamination.

11. About 120 feet up stream under a log which projected over a sandy bottom was another place where the deer were fond of standing. Here we found:

By silver nitrate test	Cl.	1050 per million
By sodium acid sulphate test, carbonates as Ca		185

12. A sample taken to the College of Mines yielded Dr. A. A. Koch:

Cl.	1298
Ca.	247
Na.	572
H_2S	0

This would give 572 Na plus 885 C.=Na Cl 1475
234 Ca plus 413 Cl.=Ca Cl_2 647

Leaving amounts of calcium (13 parts), magnesium, iron, etc., to be combined as carbonate or sulphate.

Allowing for the probable amount of such carbonates, say 238 per million, would make the total solids very much as in No. 7.

Owing to the very dry weather there may have been some concentration, and there is even more likelihood of a dilution with surface water. But specimens 9 and 12 ought not to be very much affected. Analysis 7 shows clearly the dominance of chlorides over sulphates. In the presence of calcium chloride no stress can be laid on the sodium acid sulphate test, but the water is obviously much harder than the ordinary sandstone water.

A contamination by urine of wild animals is perfectly possible in 7, 8, 10, 11, not so likely in 9 and 12. But as in any case urine contamination would raise the proportion of sodium, the presence of a water containing not less than 1,000 parts of chlorine, and some calcium chloride oozing from a Cambrian sandstone where it is exposed under a relative thick cover, and not so leached as farther north seems with great probability to be the source of these salt licks.

Other natural salt licks or springs in Michigan were described by Douglass Houghton in his early reports. C. A. Davis reports one in Section 22, Wisner township, Tuscola. Mr. Shiras says there was one four miles up Sand river from the D. S. S. & A. R. R. track, and another about 300 yards from Deer Lake, near Onota.

Mr. Henderson reports some on Sec. 22, T. 49 N., R. 40 W. Another large one on the bank of a creek in Sec. 16, T. 49 N., R. 40 W. Another one mile south of the Copper Crown Mine Sec. 4, T. 49 N., R. 41 W. Then there is a well marked one about 200 yards west of the old tramway connecting the Union Mine with the Lake Shore in Sec. 22, T. 51 N., R. 42 W.

Very respectfully,
ALFRED C. LANE,
State Geologist.

INDEX.

W.

NOTES

ON THE

GEOLOGICAL SECTION

OF MICHIGAN

FOR

GEOLOGISTS, TEACHERS AND DRILLERS

PART I. THE PREORDOVICIAN

BY

A. C. LANE AND A. E. SEAMAN

REVISED AND ENLARGED FROM AN ARTICLE IN THE JOURNAL OF GEOLOGY,
VOL. XV, NO. 7, OCT.-NOV., 1907.

INTRODUCTION.

It is not as easy to summarize the section of Michigan as, for instance, a compact state like Iowa. For one thing the state is so spread out that, turned around by its southeast corner on the map, it would reach beyond New York into the Atlantic Ocean, and turned around by its northwest corner, would extend to Hudson's Bay and into the Dakotas. Again it includes within its borders representatives of probably the oldest land masses, which have been frequently, if not continuously, above sea level ever since they were first elevated. The geological succession may therefore be expected to be interspersed with beds laid down on land and in lakes fresh and salt, and seas like the Caspian and Black, by stream and wind, as well as wave.

Part I includes the pre-Trenton rocks which even the drill has not reached in the Lower Peninsula.

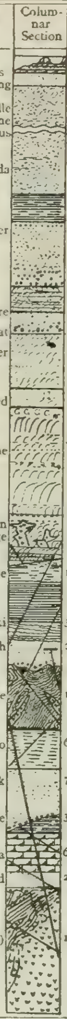
In preparing these notes the state geologist had assistance from Professor Seaman of the College of Mines as to the older rocks to such an extent that it may be best expressed by joint authorship. Indeed what he knows of the Upper Peninsula is so interwoven with what he has learned from and with Professor Seaman that anything he could write would be essentially of that nature.

With regard to the Paleozoic series he has had the advantage of the constant assistance of Mr. W. F. Cooper, and of unpublished reports by A. W. Grabau and N. H. Winchell to examine. Since, however, he differs quite materially from Dr. Grabau, and Dr. Grabau has recently given elsewhere[1] the essential features of his interpretation, no detailed reference to these unpublished reports will be necessary. It need not be said that there are many things and many divisions in the geological column upon which further light will be thrown, and it is hoped that before long the Paleozoic geology of the Upper Peninsula may receive more careful attention. But it is well to be sure one is right before going ahead in any change of names, since any such change renders reports less readable even to the geologist, much more so to the teacher, engineer, and others who make casual use of them. This is more the case when a number of new names are brought in at once. In regard to the scientific questions involved, see the article, "The Geologic Day," *Journal of Geology*, 1906, p. 425.

One general remark should be made. The point of view of the state geologist is largely that of a student of well records and of the drillings returned from them, in which the fossils play next to no part. Not only is the point of view of Dr. Grabau that of a paleontologist, but this must also be remembered, that the study of the paleontologist on outcrops is, in a broad and general way, the study of formations nearer

[1]Bulletin Geological Society of America, Vol. XIX, pp. 540-556.

their margins and more likely to be of some other type than simply marine, and if marine deposits, more likely to be deposits of the littoral, and of extreme transgression.



System	Series Name	Formation Name	Columnar Section	Thickness	Character of Rocks
Ordovician		St. Peter		0 to 75	*Sandstone;* white, waterbearing, in hollows of Calciferous dolomite, but absent often
		Calciferous		255 to 180	Buff and bluish dolomites often sandy, with dolomitic white sandstones.
	Neo-Cambrian Saratogan (Potsdam)	Lake Superior: Munising		200	*Sandstone;* white or light, waterbearing.
		Jacobsville Redstone		0 to 1500+ (4000?)	*Sandstone:* red and brown and striped with streaks of red clay shale, conglomeritic where it laps upon older formations.
		Hiatus		not drawn to	scale, the relation of the Freda to the Lake Superior Sandstone being uncertain, probably one formation.
	Upper Keweenawan, perhaps	Freda		(900+)?	*Sandstone*, red, with some felsitic and basic débris, and salt water.
	Mio-Cambrian	Nonesuch		350 to 600	*Shales:* dark, fissile beds, with dark basic fragments, and products of decomposition of lavas copper-bearing.
Cambrian or Primordial		Copper Harbor: Outer		1000 to 3500	*Conglomerate:* very heavy red, with large rounded bowlders of all lower formations, including jaspilitic iron ores, agate amygdules, gabbro aplites, etc.
	Keweenawan	Lake Shore		1800 to 400	*Traps:* basaltic lavas, and at least one—the "Middle"—conglomerate.
		Great		2200 to 340	*Conglomerate:* very heavy, like the outer conglomerate.
		Eagle River		2300 to 1417	*Group* of basic lava flows with *frequent* beds of sediment, Marvine's (c).
	Lower Keweenawan, perhaps eo-Cambrian	Ashbed		1456 to 2400± (50 sediment)	*Group* of basic lavas of the "ashbed" type with scoriaceous sediment and only 50 feet or so of conglomerate. Locally felsites
		Central Mine		3823 to 25000? (480 sediment)	*Group:* mainly of lavas of the augitic ophite type, with infrequent sediments. At the top is the "Mesnard epidote" and just beneath the heaviest flow, over 1 000 feet thick at times known as the Greenstone. Under this is the Allouez conglomerate Marvine's No. 15. No. 13 is the Calumet and Hecla conglomerate or lode. The Kearsarge Lode is shortly above 9.
		Bohemian Range		? to 9500+ (500 sediment)	*Group:* mainly of basic lavas, but with intrusive and effusive felsites and coarse labradorite porphyrites; also intrusive diabase dikes and gabbro and gabbro aplites.
	Animikean neo-Huronian	Michigamme		1000 to 4000	*Slates:* black and graphitic, and graywacke slates, passing into graywacke arkoses, and quartzites; metamorphosed into staurolite, chiastolite, garnet, and other mica schists and phyllites.
		Bijiki		300 to 800	*Iron formation or schist:* slates with cherty carbonate and soft ore.
		Goodrich		0 to 400+	*Quartzite:* with conglomerate base, and above quartzite or red and green flags also volcanic material.
Huronian	Mio-Huronian	Negaunee		1000±	*Iron formation:* cherty carbonates, altered to jaspilites, etc., with effusives and intrusives altering to hornblende schists and amphibolites.
		Siamo		600±	*Slates:* graywackes and arkoses and volcanics.
		Ajibik		700±	*Quartzite.*
		Wewe		300±	*Slate:* black largely.
	Eo Huronian	Kona		600±	*Dolomite:* with siliceous cherty and slaty (schistose) bands.
		Mesnard		250±	*Quartzite:* conglomerate and arkose.
Keewatin		(Marinescan)		1000+	Greenstone schists amphibolites, hornblende schists, sericite schists or crushed felsites, rarely ellipsoidal greenstones and slates and jaspilites, very largely cut by granites, the Laurentian, and numerous other classes of injections.

Fig. 2. Geological Column. Keewatin to St Peter.

In studying and comparing well records it is a notable fact that certain parts of the geological column seem to be persistent and easily correlated from well to well. Others vary markedly, even in extremely short distances. These are the points where the unconformities come in.

The columnar section is divided into two parts, on different scales, since the thicknesses of the pre-Ordovician units are much greater than those of the later ones. The thicknesses in the column are those derived from wells where the formation is as flat as possible and as far removed from its source. An attempt has been made to draw the column to scale, giving each formation something like its minimum thickness when not obviously cut off by erosion, unconformity, or overlap. The numbers placed along the side, however, show also the customary range up to the greatest thickness of which we can be reasonably sure. Still greater thicknesses may and often have been estimated, but in our judgment may not have had due allowance made for faulting, initial dip, or crushing.

The Keewatin-Laurentian.—These terms we take to have the same stratigraphic meaning, since the relations are of intrusive contact—the latter being applied where the areas are largely feldspathic or granitic and light colored, the other when they are mainly of basic rocks, or klastic in a good many cases, of the nature of the volcanic tuff (the "Greenstone schist" or "Mareniscan"). In Michigan at least there is comparatively little if any of the commoner types of sediment and limestones, either in their altered or unaltered condition. Many of the schists which are fine grained and slaty enough to pass for altered sediments prove really to be altered felsites, or volcanic ash, or something of that kind. There is, however, a little iron-ore-bearing jaspilitic chert and rarely genuine black slates. Early conditions of erosion before there was any land vegetation would have led to the formation of arkoses and tuffs, and there may have been less ocean of a very different chemical character, accounting for the scarcity of ordinary types of sediment. Generally speaking these rocks are more or less saturated with granitic matter, either in fine-grained aplitic or coarse-grained pegmatitic veins, but the whole rock may be a gneissoid granite. These gneissoid granite bosses generally occupy anticlinal areas, and are the typical "Laurentian." Around Marquette there seems to be a compound synclinal with argillites in the upper part and some ill-defined iron-bearing beds which may correspond to the Vermilion Range below, and a great deal of "Greenstone schists." These latter consist of hornblende and chlorite schist and amphibolites, including rarely "ellipsoidal greenstones," and sericite schists altered from felsites throughout, but especially in the lower parts next to the granite anticlinal bosses. The total thickness one can estimate not less than 1,000 or more than 5,000 feet.

By Bigsby, Maclure, etc., this formation was grouped as gneiss or granite with the hornblende slate under the term primitive; by Houghton and his assistants as syenite, granite, gneiss under the term primary; by Logan as Laurentian; by Foster and Whitney as granite rocks of the Azoic period; by A. Winchell as granitic rock of the Plutonic group; by Credner as the Lower Laurentian of the Eozoic; by Brooks and Pumpelly and many other following them as Laurentian; by Rominger as Huronian; by Van Hise and the U. S. Geological Survey as Archean (the basement and fundamental complex); by Wadsworth as the Cascade formation. Yet a glance at the various geological maps of Lake Superior shows that, however different the connotation, or meaning, and the theories of the various writers as to relationships, the areas and rocks *denoted* were mainly the same.

Of other terms the "Mona" series is referred to by Foster and Whitney

(p. 35), in the European sense, similar, but probably not identical, with the sense of the term used in the *Marquette Monograph.* That and "Kitchi" are intended to be synonymous terms, but include some areas of extra highly metamorphosed Huronian.

The term Mareniscan (*Van Hise Monograph*, 19, p. 473), appears to be a later synonym of Keewatin and it was decided by the joint committee to prefer the latter, but should further discoveries make a local Michigan term needful, may be used, as Wadsworth's term Cascade is later and included, we believe, disparate things. The "Palmer gneiss" appears to be a sheared facies of some of the Huronian members up to the Siamo slate.

It is only fair, however, to be ready in regard to so difficult a group as the earliest rocks, to accept a term even though there be some slight inconsistency or error made by the author, provided only that they are not so great as to destroy its usefulness by making uncertain its general application.

Huronian.—The name under which the pre-Cambrian rocks have been assembled in this state has varied. Among the earliest writers who derived their information from direct observation was Credner, then Professor Pumpelly's assistant, who published a paper in Volume II of this survey, and whose thesis for the doctorate was on *Die Gliederung der eozoischen (vorsilurischen) Formations-Gruppe Nord-Amerikas*[1], which is, as far as I know, the first original work published after that of Foster and Whitney. Douglass Houghton's "metamorphic" rocks were in the Huronian. Foster and Whitney, in spite of themselves, divided the formations to be considered, classing them all as Azoic, into granitic rocks (chap. iii); iron ores and associated rocks (chap. iv). Credner calls them all Eozoic, and divides them into Huronian and Laurentian, and the same divisions are used by Brooks and Pumpelly. As between the terms Azoic and Eozoic, Proterozoic, Archaeozoic and Archean we are not prepared to give a final decision.[2]

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[1]Published at Halle, 1869.

[2]A dual division of the pre-Cambrian is strongly advocated by Van Hise and is widely accepted. But F. D. Adams in the current volume (1909, Vol. XVII) of the Journal of Geology, p. 115, suggests a triple division—neo proterozoic, Keweenawan and Animikie or Upper Huronian; meso proterozoic, Middle and lower Huronian; eo proterozoic, Keewatian and Laurentian. See also Van Hise's article immediately previous in the same volume.

When a dual division is used the terms are either azoic and eozoic, (Credner and Dawson to W. B. Scott), or Archaeozoic and Proterozoic, (Chamberlin, Salisbury and Willis), Archaean and Algonkian (Van Hise and U. S. Geol. Survey), or Laurentian and Huronian (Dana and most textbooks twenty years ago).

As against the use of any "zoic" terms, Van Hise objects that as the pre-Cambrian is not fossiliferous any zoic discrimination is impossible. The factors upon which he would mainly depend are as follows: Lithological character, the younger division being more largely ordinary sediments; widespread unconformities; relations to younger rocks; relations to intrusives; deformation; metamorphism.

It has, however, been suggested in the Geological Magazine for November, 1908, that in a world where there was no life or where the land was not clad with verdure or the air or the ocean of different chemical composition, there might be such different conditions of sedimentation that without fossils the work of life could be recognized and that in this direction might ultimately be found the best grounds of division. Thus, Van Hise's objection to zoic terms may not be quite so important. Perhaps all would agree that at present the line between the two divisions of this pre-Cambrian is not drawn at exactly corresponding points in various regions.

There has been much discussion of late of desert sedimentation, by Walther, W. M. Davis, Barrell, Huntington, and others. It seems to the writer that many of the peculiarities of the desert are due, not to the arid climate *per se,* but to the fact that it is devoid of vegetation. This we now find practically only in arid lands, but before the earth was clothed with verdure, or moss or lichen existed, the land must have been bare, and even though the climate were wet the sedimentation must have been very different. In particular, without organic life there must have been little chemical denudation by organic acids. This had an effect in two ways. In the first place, the attack by CO_2 must have been limited to that in the air or supplied in igneous rocks. The streams must have been relatively low in carbonates. In the second place the sediments found by mechanical rock disintegration which is of much greater relative importance where the rock is not protected by vegetation must have been much richer in the soluble bases which are nowadays removed by the organic acids. Thus must have been produced the ancestors of the arkoses, greywackes, and sedimentary gneisses and schists, and the peculiar character of the early sediments upon which Chamberlin, Salisbury and Van Hise have commented, may have a "zoic" meaning. More than this, many have thought that the early atmosphere was free from oxygen and that the supply of this to the air is due to plant life and anaerobic bacteria. The absence of organic disintegration would leave the other kind more prominent,—the volcanic emanations of carbon dioxide, chlorine and sulphur in connection with the enormous volcanic activity of the "greenstone schists," Keewatin, formation.

These acid radicals would tend to carry off iron to the sea, if there was not oxygen to precipitate it by oxidation, though there might be some precipitation as carbonate or sulphide.

There might then have been at the end of the really azoic time an accumulation of dissolved chlorides of calcium, iron and other bases in the ocean, and of sediments, volcanic agglomerates and conglomerates, and other sediments differing but slightly from associated igneous rocks, arkoses, gneisses, mica schists.

The facts with regard to the earliest sediments and their included waters agree with the hypotheses outlined.

Such then, would be the Azoic, the earlier pre-Cambrian. Then as life came there would be a development of more ordinary sediments and waters of rivers such as now drain granite areas, with sodium carbonate and silicate in solution, would begin that precipitation of calcium as carbonates and accumulation of sodium chloride instead of calcium chloride which has been the dominant factor in the chemical evolution of the ocean. More promptly, however, the sodium silicate and carbonate would react upon the ferrous chloride precipitating the silica as chert and the iron as iron oxide, and the carbonate as siderite, leaving the sodium chloride in solution.

Thus, the lean, unaltered, not enriched ferruginous cherts of the upper pre-Cambrian may have been formed. Decaying vegetation might also produce black muds from which graphitic slates might be produced, and limestones might be formed at any stage by precipitation chemically or as in the chara limes by algal co-operation.

The ocean may have remained relatively fresh and unfavorable to the secretion of shells, and the rapid evolution of life into various branches of the animal kingdom gone on without hard parts, and without a body-cavity closed from the oceanic vital medium. But with the steady accumulation of salts in the ocean, its waters reached and passed the physiological optimum of eight parts per thousand. Numerous different branches of the tree of organic life responded to this change of environment for the worse by secreting calcium carbonate or phosphate, at first as a pure physiological or pathological necessity like renal calculi. But it at once was found to be of immense value as a skeletal support and protection. Only in some such way does it appear that we can account for the appearance of hard parts in numerous branches of the animal kingdom at about the same time. It must be due to a general reaction to some general change of environment, and this particular change, supported as it is by analyses of connate waters and the general drift of chemical evolution of the ocean, as well as by the physiological evidence so acutely marshalled by Quinton, is by far the most plausible. This event marks practically the beginning of the Cambrian. The classification which the writer would suggest as probably that of the future is tabulated below. The connotation or definition is very different from that of Van Hise, but in denotation or application the only changes needed will be to remove perhaps a small portion of that generally referred to as Keewatian, as well as the Grenville Limestone and associated beds, from the Azoic.

The terms Azoic and Eozoic may then be reserved for the two divisions of the pre-Cambrian, when one is trying to draw the line at the actual beginning of life. If some unconformity, probably not just at that time, is taken as a dividing line, then such terms as Archaeozoic and Proterozoic may be preferable.

The line between Azoic and Eozoic may be provisionally drawn at the time when the supply of water to the ocean became alkaline rather than acid and hence the accumulation of chlorides of lime, iron, and magnesia was checked. For if this was due to the first great extension of vegetation and evolution of oxygen it would account for the fact that the first appearance of massive beds of dolomite or limestone, or chert and iron or jaspilite, and of black slate is in the same series.

Such a line as we have said would probably cut out from the lower division the Grenville and the Soudan, but leave in it most of the Keewatian. Upon the practicability and desirability of drawing such a line will the permanence of such a classification depend.

SUGGESTED SUBDIVISION OF THE PRE-CAMBRIAN.

	Life Eras.	Life.	Ocean.	Land.	Atmosphere.	Formations.
	Palæozoic.	Animals with hard parts and body-cavity closed; land animals begin.	Growing salter, with Na Cl increasing.	Ordinary sediments and fossils.		Cambrian (Keweenawan).
			{ Total solids 8 per thousand. Na : Cl — 1 : 12 +			
Archæozoic or Proterozoic. Dana's Archæan Pre-Cambrian.	Eozoic.	Life important, abundant, rapidly increasing, and differentiating, vegetable life on land. Sea animals without hard parts and probably without a closed body-cavity. Anærobic forms (plants) first.	Fresh, perhaps slightly acid with volcanic emanations, unfavorable to lime secretion, but precipitating it with iron and magnesia by reaction of chlorides (or sulphates) with sodium carbonate or silicate, and perhaps by vegetation like *Chara*.	Land clothed with low vegetation, chemical composition of streams like those of the Laurentian Highlands to-day; mechanical erosion becomes less, chemical more, important. Sediments: chert, iron oxides, volcanic agglomerates, greywackes, precipitated dolomites, also the ordinary mechanical sediments and black slates. Fossils only preserved as imprints.	With oxygen from plant activity.	Neo-Huronian (Animikie). Mio-Huronian. Eo-Huronian. Logan's Upper Laurentian.
		{ Life begins at first anærobic and generating oxygen.	{ Total solids very low. Na : Cl — 1 : 60 +			
	Azoic.	Life absent or local and insignificant, probably a good part of the time conditions such as would make its wide distribution impossible.	Fresh, unfavorable to life, acid with volcanic emanations; chlorides accumulate. Sulphates reduced to sulphides by ferrous iron (?) from basic rocks, hydrocarbons accumulate.	River-water fresh, with little tendency to leach out the alkalies exclusively. Surface uncovered, exposed to very rapid mechanical action.	Free from oxygen with CO_2, H_2O, etc.	(Most of the) Keewatian, Greenstone schists, gneisses.
			Resultant sediments mechanical, not unlike in chemical composition to the rocks from which they were derived, no organic rocks (like black slates), no leached iron ore, no true massive stratified dolomites, volcanic rocks abundant. Atmosphere not oxidizing, red rocks absent?			(Coutchiching, if it exists, as the writer does not think.)

The terms Laurentian and Huronian have been used pretty continuously in the Lake Superior region, and always with almost the same practical application, so far as this state is concerned. We think, therefore, that we should in them follow Credner and Logan, though it may be better to replace Laurentian by Keewatian. It is at present agreed to divide the Huronian into three series. A question may arise whether the lowest of these series, which is considerably older than the other two, more eroded, and quite different in distribution, may not be the Grenville or Upper Laurentian. There is, however, no local ambiguity involved, as it has always been mapped with the Huronian in this state.

Eo-Huronian.—We use this term in preference to Lower Huronian, as that was applied to the eo-Huronian and mio-Huronian until the threefold division of the "Marquette" series was recognized. The *Marquette Monograph* calls it Lower Marquette. We had always called it Mesnard (formation or series).[1] The U. S. and state survey now restrict this name to the basal member.

a) Mesnard quartzite. Well exposed on Mt. Mesnard just south of Marquette; finely ripple marked. About 250 feet of slaty flags. Toward the base is a conglomeritic and arkose quartzite.

There are also brecciation beds, slate, quartzite, and cherty quartzite toward the Kona dolomite above.

It is at times much metamorphosed and sheared and may be confounded with underlying beds, and is at times cut by granites, but by no means as commonly as the Keewatian. We think, too, the granites cutting the Huronian have a different character, being more inclined to a coarse porphyritic facies.

b) Kona dolomite, 600 ft. This is a very well marked horizon around Goose Lake, but is represented, we believe, on all the ranges and in the original Huronian, being the Randville dolomite of the Menominee Crystal Falls region, and the Bad River formation of the Gogebic Range.[2] Extensive erosion took place before the deposition of the mio-Huronian, generally removing the slates above it and often cutting deep into the dolomite.

c) Wewe slates, 300 ft. The slates of Goose[3] Lake, rarely left by the erosion, but exposed on Carp River, Sec. 5, T. 47 N., R. 25 W., and on Sec. 12, T. 47 N., R. 26 W., black and gray slates.

Mio-Huronian.—This we are inclined to believe is the main iron-bearing formation, not only of the Marquette range, but of the Menominee range as well. During this time began an epoch of extrasion of basic volcanics at numerous points which continued into the neo-Huronian and expressed itself mainly in intrusives altered to amphibolite ("diorite"), chloritic schist, "paint rock," and uralite diabase in the mio-Huronian, and mainly in effusives and tuffs in the neo-Huronian.

This is Van Hise and Leith's Middle Marquette; compare also Wadsworth's "Republic" and "Negaunee" formations.[4]

a) Ajibik quartzite, 700 ft. Has often been confused with Mesnard quartzite. Grades upward through slaty phases into *b*).

[1]1892 Report, p. 65.
[2]Rominger's "Marble" Series, Vol. IV, p. 56.
[3]Wewe is Chippewa for "goose."
[4]Though he was never quite able to agree with what seems to us the proper interpretation of the stratigraphy of the same, so that the order as given on p. 66 differs so much from our views that we could hardly use it without producing confusion. See 1892 Report, pp. 64, 66, 110, etc.

b) Siamo slate, 600 ft. Grits, flags, and graywackes, and graywacke slates, with volcanic tuffs.

c) Negaunee formation, 1,000 ft. The main formation of cherty carbonates and siliceous beds with "greenalite" readily altering into jaspilitic iron-bearing formation.

Near igneous contacts it also changes into grünerite, and other amphibole-magnetite schists.

Neo-Huronian (Animikie).—The relation of this series around Port Arthur on the north side of Lake Superior and along the Gogebic range on the south are such, both as to the overlying and underlying rocks, that there can be but little doubt that they are in general coeval, and the graphitic slate horizon of the upper part seems to be widely identified. We have no hesitation in adopting the term Animikie. There may be some question as to whether it belongs in the Huronian at all. We believe Lawson considers the greatest and most profound unconformity[1] to come at the base of this formation, rather than for instance, between the Mesnard and the Keewatin or greenstone schists; Adams, too, emphasizes the unconformity below, and it must not be forgotten that the Minnesota Survey has held it to be Cambrian.[2] Were the Gogebic range alone to be studied we might agree with Lawson, but there the unconformity at the base of the Animikie represents the elimination of all of the mio-Huronian and most of the eo-Huronian, thus representing a good part of Huronian time. Without question the Animikie is much less disturbed than the older formations, but we are not prepared to say that any one of the breaks before the Keweenawan is the "essential break."[3]

The divisions are:

a) Goodrich quartzite, 400 ft. This is represented on the Gogebic range by the Palms formation of red and green quartzose slates. But there, as on the Marquette range, there is a conglomerate base, containing pebbles of jaspilite and dolomite as well as granite. Basic tufaceous material is a sign of local volcanic activity, which continued from mio-Huronian (part of Clarksburg formation, etc.) near foci of which the formation may be very thick.

b) Bijiki formation, 300 ft. This is a cherty, iron-bearing member with graphitic slates, on the Gogebic range some 800 feet thick, known as the Ironwood formation and the main iron member. It was not considered in the *Marquette Monograph* so persistent as we believe it really is.

c) Michigamme slate. A group of black, graphitic slates and graywackes, quite wide spread—the Tyler slate of the Penokee-Gogebic range, the Lake Hanbury slates of the Menominee Range. Usually not over 1,000-2,000 feet thick. On the Gogebic range apparently, 4,000 ft.

Keweenawan.—The term Keweenawan used as a technical name for a rock series is nearly synonymous with Nipigon, which has a year or so priority, but was introduced practically simultaneously in two slightly different senses; and the term Keweenawan has been so much more widely used that the joint committee agreed to retain it. Douglass Houghton included the Lower Keweenawan up to the Great Conglomerate under the

[1]The Eparchean interval.

[2]But Logan and Hunt in the original introduction of Huronian—*Esquisse Geologique*, p. 28—considered Huronian as Lower Cambrian of Sedgwick. At that time, as in the earlier editions of Dana, the Potsdam was classed as Silurian.

[3]Leith in A. I. M. E. Trans., 1906, p. 128.

general head "Trap rocks" and understood that "strictly in their chronological order" they came after the "metamorphic" slates and quartz rock. The Lake Shore traps were thought of as intrusive dikes, so that he could group the Greater and Outer Conglomerate together under the head "conglomerate" and the rest of the Keweenawan above as "mixed conglomerate and sand rock." Foster and Whitney followed his divisions in their mapping, including them as the lowest divisions of the Silurian (which, as in the early editions of Dana, was understood to go down to the Azoic and include the Primordial) and as intimately associated with the Lake Superior sandstone, so much so as not to need any separate formation name. It has already been mentioned that the latter has been referred to various ages from Triassic back. Logan called them the "Upper copper-bearing" rocks; Brooks and Pumpelly the Latin equivalent "Cupriferous," and considered the formation conformable to the Huronian, but covered unconformably by the Lake Superior sandstone, and likely to be more allied to the former than the latter. Irving introduced the term Keweenaw(an), and in *Monograph* V, p. 24, recognized an unconformity (disconformity) of the Keweenawan and Huronian, as well as an unconformity above, especially with the Mississippi Valley Cambrian sandstones. Neither of the unconformities do we doubt. But they appear to be with basal Keweenawan beds disturbed by coeval volcanic activity and faulting, and seem to us quite comparable with inter-Keweenawan phenomena, while the Lake Superior sandstone and the Upper Keweenawan appear to us closely associated not merely lithologically but stratigraphically.[1] We prefer, therefore, for the present, to place the Keweenawan in the Cambrian to express that fact. If we could but be sure that there was indeed a universal cycle of sedimentation and rhythm of geological activity, by which, all the world over, crustal rearrangements and volcanic activity took place simultaneously, while at other times atmospheric conditions universally favored the deposit of limestones or black shales, there would then be more of a temptation to compare our column with the type column in Great Britain and see in the

Longmyndian red sandstone and volcanics	the correlates to the Keweenawan.
Longmyndian flag stones and shales and Russian schists	the correlates to the Animikie black slate and graywackes.
Bradgate, Beacon Hill and Black Brook hornstones of Charnwood Forest	the correlates to the Huronian cherts and jaspilites.

The Keweenawan would then indeed be pre-Cambrian. But far-off lithological correlations have too often proven a will-of-the-wisp.

There are practical advantages in grouping the upper part of the Keweenawan which has no igneous intrusive or effusive rocks and no copper, with the Lake Superior sandstones which are similar, because then the copper bearing Keweenaw Range can be better brought out in mapping.

[1]See Annual Report, Board of Geological Survey of Michigan, 1904, p. 143.

ARGUMENT FOR CAMBRIAN AGE OF KEWEENAWAN.

1. The main argument for the Cambrian age of the Keweenawan is that the Upper Keweenawan and acknowledged Cambrian are so closely affiliated:

(a) Lithologically.—both red sandstones with much material other than quartz and red shaly beds.

(b) Structurally.—both faulted, not folded, except in a very broad way, as part of the Lake Superior synclinal. Thus they were naturally by the early writers taken as the same, and the burden of proof rests on the one who says they are not. It is probable that new observers, even those who believed in the pre-Cambrian age of the Keweenawan, who visited the Sault, Marquette, Jacobsville, Apostle Islands, Clinton Point, (Fig. 3,) Freda, the north shore of Lake Superior, and the south shore of Isle Royale, would be quite erratic in the points they assigned respectively to the Cambrian or pre-Cambrian.

2. No intrusives such as cut or are effusive in the Middle and early Cambrian in various places cut the Upper Keweenawan,—but such diabases and melaphyrs do sometimes most strongly resemble Keweenawan igneous rocks.

3. It is improbable that a *very considerable interval* should elapse with *no deposition*, and that then it should begin again with so similar rocks as the Lake Superior sandstone and Upper Keweenawan and with so little evidence of erosion of the Upper Keweenawan, valley trenching of the same, etc.

4. No basement conglomerate to the Cambrian against the Upper Keweenawan has been discovered, whereas there is a very strong one, containing a wide variety of pebbles of the intrusives as well as extrusives of the Lower Keweenawan at the base of the Upper Keweenawan.

OBJECTIONS TO CAMBRIAN AGE OF KEWEENAWAN.

1. The unconformable overlap of the Potsdam (Eastern or Jacobsville and St. Croix) on the Keweenawan.

Answer: This is against the Lower Keweenawan and is to be expected if the later is an igneous and largely a land formation forming and eroded during the Cambrian transgression.

2. The continuation of the pre-Cambrian peneplain over the Keweenawan.

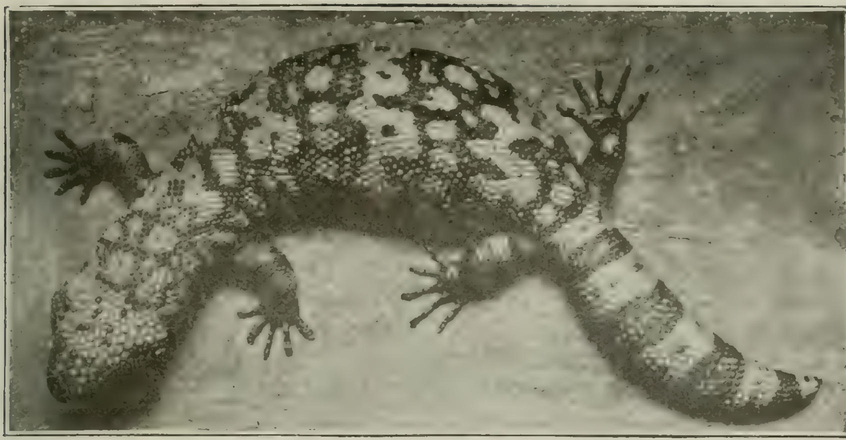
Answer: Is it pre-Cambrian or pre-Potsdam or possibly Cretaceous? And does it really so continue? Weidman, I believe, thinks not. Does not the peneplain in question include the Niagara limestone of Limestone Mountain?

3. The lack of fossils.

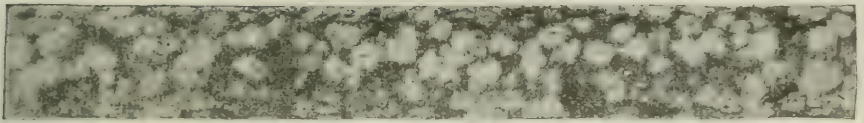
Answer: This is true also generally of red sandstones and of land and fresh water formations, and would be the more true in a *volcanic* and arid region, and *at a date when land animals* are not known to have existed.

4. The presence of pebbles of Keweenawan in the Cambrian along the Keweenawan fault shore cliff.

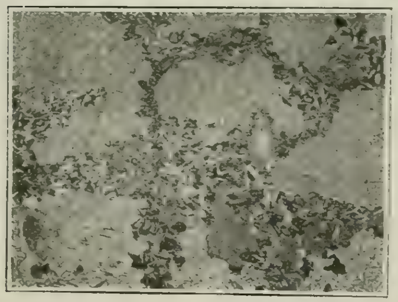
Answer: This is true *also* of most of the Keweenawan conglomerates



(a) In Gila Monster.

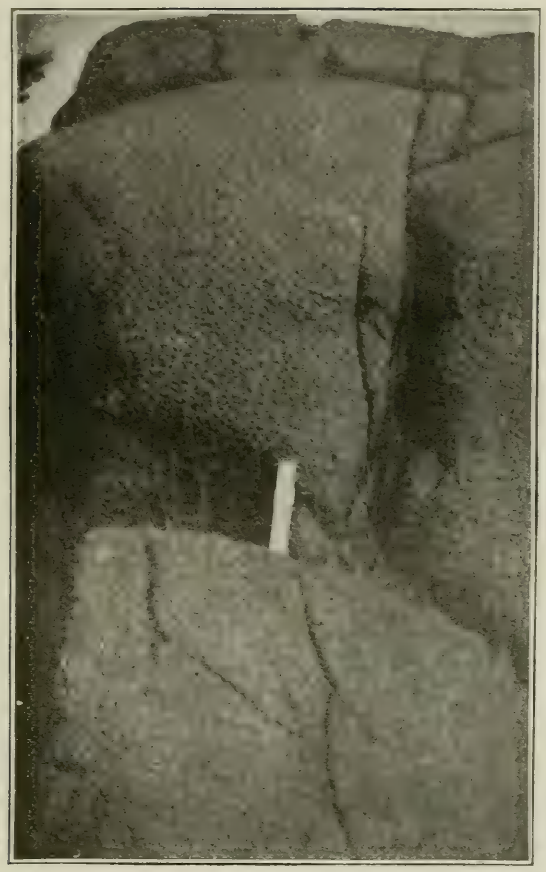


(b) In diamond drill core.



(c) In thin section.

ILLUSTRATIONS OF OPHITIC PATTERNS.



OPHITIC TEXTURE IN WEATHERED EXPOSURE OF "GREENSTONE."

Photograph by W. J. Penhallegon.

See Bull. Geological Society America, 1908, pp. 644-648.

and shows merely that the formation was exposed to erosion during its formation.

5. The greater amount of disturbance of the Keweenawan.

Answer: Too great weight cannot be laid on this in a volcanic series, but it is noteworthy that the Keweenawan shows a steady approximation to the Cambrian in such respects (freedom from faults, intrusives, effusives, and from high dips) as one ascends in the series.

6. The lithological difference between the Keweenawan and the early Cambrian elsewhere.

Answer: This is really entirely in accord with our conception of the Keweenawan according to which we should parallel the Keweenawan contrast to the marine early Cambrian, Georgian and Acadian with the new red sandstone and red Permian with their effusives in Germany, contrasting with the Alpine marine Trias, and again with the Scottish Old Red sandstone contrasting with the south of England Marine Devonian.

I think a careful study of the lithologic character of the *nearest early* Cambrian and the intrusives cutting the same might even lead to strong arguments in *favor* of the Cambrian age of the Keweenawan.

A trip in 1908 brought out this difficulty of drawing the line between the Upper Keweenawan and the Cambrian sandstones.

On July 21st (1908) I visited the Houghton-Hancock section with Leith and Martin. We saw the conglomerates dipping 50° to 60° back of the Upper Range station, then walked to the abandoned Atlantic mill crossing numerous traps, toward the end more numerous and less steeply dipping conglomerates, and at the end where the road turns up hill to the Atlantic Mine exposures of red sandstone and shale where the dips were still over 30°.

Then taking ferry to the Hancock side of Portage Lake we saw the Nonesuch beds and the old quarry exposure near the powder houses, black shales and fine grained conglomerate sandstones with dip of 35° and less. We also saw similar sandy beds up Swedetown Creek.

That afternoon we visited Freda, finding a section of over 40 feet red micaceous shales and impure red conglomeratic sandstones shelving, dipping less than 10° to the lake. The Freda well showed over 900 of such beds with a salt water at the base.

We left that night for Saxon, and the next day, July 22nd, we walked about 5½ miles north to the Lake Superior shore, repeating a trip I made earlier in the season. About two miles north we passed a heavy conglomerate, well exposed both in the road and in a ravine nearby. This is presumably the Copper Falls Conglomerate (outer conglomerate) underlying the Nonesuch shales. After this the road descends rapidly until about 100 to 200 feet above the Lake. Fig. 3.

Descending into the Oronto valley from this level we found a short distance from the lake a considerable section of red impure sandstones and shales dipping about 52° to the lake.

Taking boat to Clinton (locally called Marble or Cemetery) point we found a set of low ledges, lithologically similar, ripple marked and mudcracked with a somewhat contorted cross bedding in places, but on the whole dipping 9° to 15° and at times more to the lake. These Irving classed as Cambrian.

Thence we passed to the mouth of the Montreal river. This is crossed by red shales and sandstones striking with the coast toward Little Girl Point and dipping something like 65° and more toward the lake.

This section continues to and above the falls for several hundred feet, after which a gap with no exposures occurs in which a fault, parallel to that at Keweenaw Point, *might* pass.

Then at the log bridge begins another section of red impure sandstones and shales nearly vertical, dipping perhaps 85° to the lake, followed after a few thousand feet by the Nonesuch shale group and the heavy Copper Falls conglomerate beneath containing pebbles apparently from the Keweenawan formations beneath, red rocks, porphyrites, etc., as well as of the jaspers and other beds of Huronian.

The exposures are not continuous enough to speak with certainty, but so far as anything we saw, the Clinton Point series, which is lithologically similar, seems structurally analogous to the Freda sandstones and might be included in the Upper Keweenawan, and yet Irving included it as Cambrian.

There is no reason why there may not be some apparent expansion in the thickness of these beds by repetitive faulting analogous to that on the south side of the Keweenaw Point Range.

The information additional to that contained in Irving's Monograph[1] is as follows:

(1) The decidedly northwesterly dip at Clinton Point, the shore here being very rapidly retreating and probably not so well exposed thirty years ago;

(2) The intermediate dips on the Oronto river;

(3) The lakeward dip of the Montreal river section and the *interval with no exposures* admitting the possibility of faulting as suggested by the coast.

Lower Keweenawan.—The conglomerates which occur at the top of the Lower Keweenawan and below the Lake Shore traps may perhaps belong stratigraphically to the Upper Keweenawan. They contain a wide variety of pebbles and large bowlders.

The main part of this formation cannot at its thinnest point be put down as much less than 15,000 feet. Its base in contact with the upper beds of the Animikie formation has recently (H. L. Smyth) been found north of the Gogebic range. Here its thickness appears to be near 42,500 feet, and I do not think it can possibly be reduced by any allowance for repetition by faulting and initial dip to less than 29,000 feet. Some such thickness of rock with the specific gravity of trap over against an equal thickness of granitic rocks would be needed to produce isostatic equilibrium between the bottom of Lake Superior and the Huron Mountains. The general characteristic of the lavas which made it up is that, while they run from silicious felsites and quartz porphyries to quite basic rocks, there is nothing ultra basic nor ultra alkaline known. Porphyritic crystals are mainly quartz and feldspar. These have normally crystallized earlier in the magma. A marked second generation of augite is almost unknown. Of the thickness only a small fraction is sedimentary and that of a type which may be rapidly accumulated, so that the accumulation of the whole series does not necessarily mean great dura-

[1] U. S. Geological Survey, No. V.

tion. When we come to estimate how much is sediment, we find that continuous diamond-drill sections indicate for the major part of it less than 7 per cent. (5.65 per cent. in 8,500 feet near Portage Lake, 6.65 per cent. in the 6,247 feet at Isle Royale.) The greater the thickness probably the less the percentage. Making detailed allowance for the Great and certain other heavy conglomerates at the top, we get 4,250 feet for the sediments alone—conglomerates and sandstones of very rapid deposition for the most part. A detailed section is given in the *Black River Report*, Annual for 1906, p. 400. Fairly persistent (Isle Royale, Black River, Keweenaw, Mamainse) appear to be the following divisions of the Keweenawan beginning from below:

1. **Bohemian range group.** (Irving's (1) and (2), Plate XVII) characterized by numerous flows of labradorite porphyrite type and felsites near the top and frequent intrusions of straight-walled diabase dikes, of felsite, of gabbro and affiliated fine grained red rock, (gabbro aplites). North of Bessemer, the thickness, igneous sills included, is . . . . 9,500 ft. There may not be 500 feet of sediment.

2. **Central (Mine) group.**—Including the "Greenstone group," the "Phoenix Mine group," etc., but only a part of Pumpelly's "Portage Lake series." Just about that part of the formation included and well exposed in the workings of the Central mine on a cross-fissure, exposing a good section, examined by Pumpelly and Hubbard, and more recently supplemented by diamond-drill cores on the same property (sections 24, 25, 36, T. 58 N., R. 31 W.) This part has also been developed in the Clark, Empire, Mandan, Manitou and Frontenac, Cliff, Calumet and Hecla and Torch Lake, Franklin Arcadian, Isle Royale, Winona, Lake, Adventure, Mass, and Victoria sections. This is a new name we would introduce and define as extending from the Bohemia conglomerate, Marvine's conglomerate (8) to the "St. Mary's epidote," a sediment (volcanic ash) just above the "Greenstone" which is above Marvine's conglomerate (15.) Characterized by very heavy flows of ophite.[1] some of them hundreds of feet thick, so that, for instance, the "Greenstone[1]," the one at the top of the series, extends beneath Lake Superior, from one side to the other; often proportionately coarse grained.

On Black River there are possibly 25,000 feet including flows. At Portage Lake (5,913), say 6,000 feet.

3. "**Ashbed**" **group.**—This group has been named from the Ashbed Mine, or really originally from a lode so called by the miners, worked at that mine, Marvine's (*a*) and (*b*), Irving's (5) and (6). Including conglomerates 16 to 18, characterized by frequent glomerophyrites, that is relatively feldspathic and fine grained flows with less lime than the ophites, and volcanic agglomerates of the a a type.

In the Tamarack shafts . . . . 2,400 ft.

At Eagle River according to Marvine (*a*) 925 + (*b*) 618.

The amount of well-marked conglomerate is not over 50 feet but the amygdaloids shade into beds of scoria mixed with red mud called "ashbeds."

4. "**Eagle River**" **group.**—Marvine's (*c*), characterized by a waning of volcanic activity shown by the numerous (10 or more) sandstones and conglomerates, while the interbedded flows are more of the normal type.

[1]See Plates.

In the upper 2,700 (1,417) feet Marvine estimates 860 feet of sediment. On Black River it is given as 1,417 feet, at the Tamarack as 1,700 ft.

5, 6, and 7. **Copper Harbor conglomerates.**—The conglomerates north of the Eagle River Group were grouped together by Douglass Houghton, who considered the Lake Shore Traps as intrusive dikes. When these were understood to be interbedded flows, the conglomerate was divided into the Great and Outer, respectively, below and above the Lake Shore traps. Hubbard's studies around Copper Harbor have shown that there are at least three heavy conglomerates. It is not probable that the lines between the Great Conglomerate, Lake Shore Trap, and Outer Conglomerate can be everywhere drawn consistently. Together they cover the period of decadent vulcanism, and it is not at all likely that the flows from these last expiring throes filled the whole basin but more likely they occur irregularly in the conglomerate series. It therefore seems fitting to give a local term to the whole assemblage, treating the Lake Shore traps as a lentil or lentils in the same.

5. **"Great" Copper Harbor conglomerate.**—Its thickness, not allowing for initial dips, is say 2,200 feet at Eagle River and Calumet, but apparently much less, 340 feet, on Black River. It has a wide variety of pebbles, but mainly of Keweenawan rocks.

6. **Lake Shore Traps.**—These are apparently thickest near Copper Harbor where using Hubbard's figures, they are about 1,800 feet thick. They are near 900 feet thick at Calumet, but at Black River are only about 400 feet thick. There is at least one well-marked conglomerate in the group. Above this group the line drawn by Irving, between the Upper and Lower Keweenawan marked by a cessation of volcanic activity. There are also in general, less dips and a greater variety in detritus.

7. **Outer conglomerate.**—With pebbles representing all the Lower Keweenawan types, including intrusives, amygdules and agates, and also the Huronian jaspilites. Only 1,000 feet are given at Keweenaw Point, but to the Nonesuch shale on Black River it must be much thicker, not allowing for initial dip at least 3,500 feet. Irving estimates 3,000 feet in the Porcupines.

8. **Nonesuch formation** (from the Nonesuch mine).—Dark colored shales and sandstones—owing their dark color to the basic material[1]—a very significant sign of heavy erosion of Keweenawan traps at some distance. This seems to be a very persistent horizon in lithological character, in spite of not being very thick, being 600 feet on the Porcupines, 500 feet on Black River, and 350-400 on the Montreal.

9. **Freda sandstone.** "Main body of sandstone" or "western sandstone" of Rominger (*not* Irving). This seems to need a local name and may well take it from the new stamp-mill town on the shore of Lake Superior, not far from Portage Lake Canal, near which exposures occur, and a well showed a thickness of over 970 feet of sandstones and shales. The relation of this to the "Lake Superior sandstone" in general is a mooted question. It was included in it by early writers. It is much like it lithologically and structurally though less quartzose and felisitic, and basic débris and streaks of red clay may be rather more common

[1]Analysis of a sandstone from Point Houghton, Isle Royale, is given in the Minnesota reports. Numerous analyses of the Apostle Islands (Cambrian) sandstone are given in the Wisconsin reports. The Portage redstone anlysis is found in report for 1892, p. 157. They are given here tabulated.

and the water more saline than in the Lake Superior sandstone around Marquette.[1] The one mantles a granitic boss from which the other was

Lake Superior Sandstones.

	1. Portage Lake "Redstone."	2. Marquette.	3. Isle Royale s w of Siskowet Bay.	4. Nonesuch Sandstone.
Silica SiO_2	82.60	77.18	75.19	63.09
Alumina Al_2O_3	8.32	9.69	10.78	18.58
Ferric oxide Fe_2O_3	0.28	3.20	4.01	2.17
Ferrous oxide	....	....	1.05	2.73
Magnesia MgO	0.18	1.48	0.95	2.67
Lime CaO	0.55	0.26	2.36	....
Manganese oxide MnO	0.13	....	....	MnO_2 .22
Soda Na_2O	6.49	0.18	1.93	4.54
Potash K_2O		4.67	0.93	.54
Phosphoric acid P_2O_5	0.05	0.21	....	.12
Sulphuric anhydride SO_3	0.31	0.23	....	....
Water	0.99	2.90	1.42	2.69

1 and 2, by F. F. Sharpless report for 1892, p. 157. These are regarded by everyone as Cambrian.

3, by J. A. Dodge, for Minnesota survey, has always been mapped as Keweenawan.

4, by C. R. Gysander (Cochrane Chemical Co.) of Nonesuch Shale. Thin section is much like that figured by Irving.

COCHRANE CHEMICAL Co.

Everett, December 13, 1907.

Analysis of Shale sample through Mr. A. C. Lane, Lansing, Michigan.

First piece of rock submitted.

Silica	63.09	
Alumina	18.58	Copper, palladium and sulphur large trace. (Cu found = .008%
Ferric oxide	2.17	
Ferrous oxide	2.73	
Titanic oxide	.99	
Manganese dioxide	.22	
Lime	1.11	Calculating P^2O^5 as apatite. Cl = .011 Fl. = .021.
Magnesia	2.67	
Soda (caustic)	4.54	
Potash (caustic)	.54	
Phosphoric acid	.12	
Water	2.69	
	99.45	

The copper had gone in solution with Ammon. Sulph. The insoluble residue from Am^2S contained *no Cu whatever* but gave reaction for Palladium (too little to weigh). 10 grm. rock were used for the determ. of Cu. All weighings throughout were made by the vibration method to 5 places of decimals and with carefully standardized weights. The second piece of rock was not identical with this first piece as it gave a copious precipitate with H^2S which proved to be principally Palladium with a trace of copper and possibly some other platinum metal. I have been unable to find gold in it.

C. R. GYSANDER.

separated, as the Nonesuch shale shows, by extensive exposures of Lower Keweenawan.

Wells in unquestioned Lake Superior sandstone at Lake Linden and Grand Marais show that it is over 1,500 feet thick. The dips are gener-

[1]Analysis of a sandstone from Point Houghton, Isle Royale, is given in the Minnesota reports. Numerous analyses of the Apostle Islands (Cambrian) sandstone are given in the Wisconsin Reports. The Portage redstone analysis is found in report for 1892, p. 157. They are given here tabulated.

ally less than those of deposition, so that we cannot make much use of them. Irving estimates the thickness of Copper Keweenawan at 15,000 feet, but this is, we believe, based on the Montreal river section in which as above said we suspect a repetition by faulting. We do not, however, think, that the Freda sandstone will be decreased below 4,000 feet, even if we allow 1,500 feet to the Lake Superior sandstone and make 8,000 feet for the whole upper Keweenawan. We repeat that we are not at all sure that there is any other than an arbitrary dividing line between it and the sandstone which we propose to call Jacobsville.

Lake Superior sandstone.—This term was used by Houghton, and has been customary since, the term Sault Ste. Marie sandstone being much

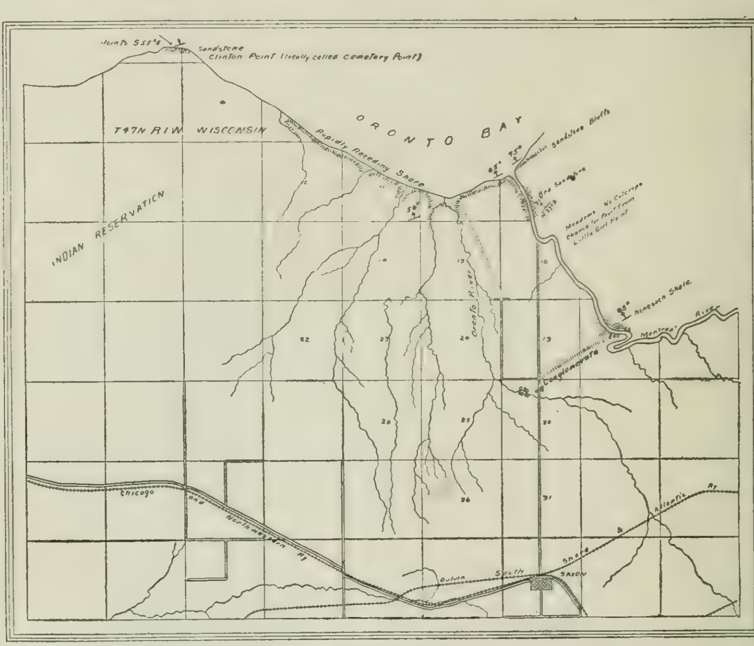


Fig. 3. Outcrops near Oronto Bay and Wisconsin Michigan line.

later and less used. It is often and quite properly called the Potsdam. It is necessary only to refer to the supposed equivalence with the "New red" Triassic sandstones which was held by Jackson, Marcou, and for a time Bell. But accepting its approximate equivalence and its continuity with the Potsdam, there still may be a quesion as to its exact horizon, which can not be exactly the same everywhere, and might be widely different. It is readily divided in outcrop and in wells into a redder and lower portion and a whiter upper portion. The line between the two may mark the epoch of submergence of the iron-bearing rocks, only a few islands of granite and quartzite remaining exposed to erosion. In view of the uncertainty of the relation of the three parts of the Lake Superior sandstones, as used by Houghton, separate names seem to us likely to be useful, and we propose not only the term Freda sandstone for that west of the Copper Range, but the term Jacobsville (from

Jacobsville where the famous quarries of Portage redstone occur) sandstone for that east of the Copper Range, and we suppose this term may apply to all the Lake Superior sandstone skirting the coast at intervals to Grand Island, while the term Munising sandstone is to apply to the upper 250 feet of Lake Superior sandstone which crosses the bluffs back of Munising, dips southerly, and is white or light colored. Houghton considered the upper "gray sandstone" (700 feet ?) to be unconformable on the lower, dipping south to southeast, while the lower dips to the north. The upper part is well ripple-marked, cross-bedded, friable, with *Fucoides* (?) *duplex* and *Lingulepis prima,* and *L antiqua. Dikelocephalus misa* (?), *Dikelocephalus* (Hall, Pl. XXIII, *3a-e,* 4), and *Lingulepis primiformis* occur at Iron Mountain in the Ptychaspis zone. At Marquette Murray reports *Pleurotomaria·laurentina* (?) and Scolithus and beds similar at Campment d'Ours close under the Trenton. At Limestone Mountain, below the fairly extensive Trenton fauna, are

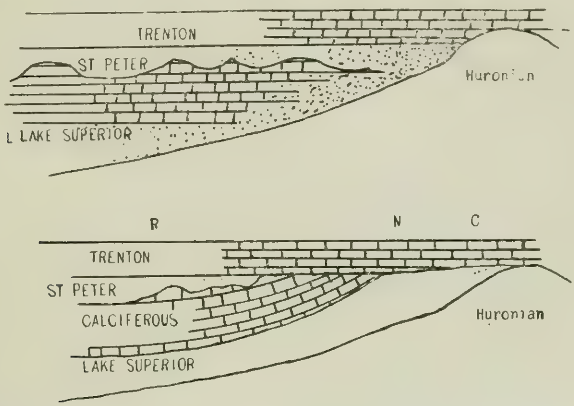


Fig. 4. Illustrates two possible interpretations of the section from Rapid River to St. Mary's River. In the one case a slight folding is assumed, in the other case a mere disconformity.

some conglomeritic beds before we come to the main mass of sandstone. Logan (followed by Grabau)[2] mainly on the strength of the (en)Campment d'Ours Island section concludes that the Lake Superior sandstone may "represent the Chazy, Calciferous, and Potsdam." Beside the Campment d'Ours Island section the Neebish well also indicates a great thinning of the section below the Trenton to the pre-Cambrian along St. Mary's river. But the question remains whether it is by a disconformity and erosion of the Calciferous and St. Peter's down to the Lake Superior sandstone, so that at least most of the sandstone below the "Trenton" limestone is Cambrian and represents the Lake Superior sandstone generally, or whether this sandstone represents the St. Peter's sandstone, the "Potsdam" and Calciferous having been overlapped, or the latter by a shoreward change of facies passed into a basal sandstone, which might represent continuous transgression of the ocean. The St. Peter sandstone is well marked at the Wisconsin line, with

[2]Bull. Geol. Soc. Am., Vol. XVII, pp. 582, 617.

a good 200 feet of Calciferous (Lower Magnesian dolomite) under it and occurs also, at intervals along Green Bay, at least as far as Rapid River. The Calciferous certainly continues as a thick, well-marked formation well beyond Calciferous station and creek, and according to Rominger clear to T. 45 and 46 N., R. 1 W., and Neebish (Anebish) Rapids. Moreover a few scattered wells to rock as at Newberry in the center of the peninsula do not record any St. Peter's. All these facts favor the first interpretation independent of the fact that it seems to fit better with Berkey's interpretation of the St. Peter sandstone, though to be sure it implies a disconformity at Campment d'Ours Island.[1] The figure just above (4) shows the two view points, the upper diagram representing the second interpretation which is favored by Grabau, the lower the view taken here.

As has been said the total thickness of this sandstone and the extent to which it is equivalent to the Freda and Upper Keweenawan sandstone are conjectural. As it laps upon the areas of older rocks its thickness diminishes to nothing, and there is often a conglomerate at its base. Its composition is largely quartz and feldspar of the acid varieties sometimes up to 37 per cent. of orthoclase and microcline. The absence from the formation, except immediately at its contact with other formations, of much basic or even a large amount of felsitic débris which is more abundant in the Upper Keweenawan, is one of the reasons why we believe there can be no great discordance or time interval between this and the Upper Keweenawan. It seems to mark the culmination of the same general transgression, when only the granite cores were exposed and finally even these were covered. The upper sandstone which Houghton called the "gray sandstone" he estimated at 700 feet thick. Wells indicate only some 250 feet.

Calciferous formation.—This formation appears to have been called by Houghton the sandy limerock, and was said to occur at several points on Sailor's Encampment Island (not Campment d'Ours) near West Neebish Rapids. On Foster and Whitney's map of Lake Superior it was called the Calciferous, a name which it has since generally retained (Winchell's map, 1865, Brooks, Pumpelly, and Rominger's map 1873, and the state survey since, *U. S. G. S. Monograph 36*, 1899, etc.), and has indeed become imbedded in the local nomenclature of Calciferous Creek, a branch of the Au Train river, and Calciferous, a station on the Marquette and Southeastern R. R., so *that it may be retained even as a geographic name.* "Lower Magnesian limestone" has from time to time been used as synonymous. The Hermansville limestone of the *Menominee Special Folio and Monograph*, pp. 31, 494 (Bayley, 1900-04) is this formation, or some part of it. It is given as not over, but near to, 100 feet thick, and equivalent to the Chazy and Calciferous of the east on Rominger's authority. The wells along the Green Bay shore, however, show a fairly constant maximum thickness of about 250 feet. Here flowing wells reach the Lake Superior sandstone between 600 and 700 feet. A late record from Marinette shows, however, 75 feet of white sandstone at the top which may be a trough filled by St. Peter sandstone. The interesting record is in brief:

[1]Cf. Rominger, Vol. I, Part 3, pp. 64, 76, 77, 82, and 83.

Quaternary sand	69- 69
Galena and Trenton	256-325
Blue and brown limestones and dolomites.	
Sand at 260′, red shale at 202′ (St. Peter horizon?)	
St. Peter (?)	
White sandstone	75-400
Calciferous	
Brown dolomite	60-460
White sandstone	70-530
Dolomite (Hermansville)	50-580
Lake Superior sandstone	
Upper, white sandstone	195-775
Lower, pink, shading into conglomerate of cherty quartzite, base uncertain	95-870
Huronian	
Cherty quartzite?	108-978

Another recent well is Rapid River well No. 2. See letter of W. H. Hobbs, Aug. 7, '07. Seven miles northeast of Rapid River, Michigan. Owner, A. E. Neff. Clippings and record in Houghton. Cisco, driller. One sample dolomite with dog tooth spar crystal and "gum" near.

TRENTON.

Top limestone 12 ft. to 230. 1904	
Dark, mixed, some sand.	
Limestone	230-290
Mixed brown and blue.	

ST. PETERS.

Sand	302-320
Round quartz sand, white.	

CALCIFEROUS.

Limestone	320-355
Fine grained, white, massive.	
Sand	400-420
Clean, white, quartz sand.	
Sandy lime	420-430
White powder.	
Sand	430-450
Clean white quartz sand.	
Sand	450-475
White dolomitic powder.	
Sand	475-500
Quartz and white dolomite mixed.	
Sand	500-530
Sand cemented by dolomite.	
Slate (cased 9 5-8 in. pipe)	530-555
Dull bluish.	

LAKE SUPERIOR SANDSTONES, MUNISING SANDSTONE.

Gray, sandy	630-675
Round quartz and rarely other gr.	
Red sandstone	675-710
Light pinkish quartz grains.	
White sand	710-725
White quartz grains.	
Red sand	725-750
Pinkish quartz grains. "725 grit."	
Water flow.	
Sand	
Mica, quartz, feldspar, etc., mixed.	
Sand	780-830
12-304 Land as here.	
Mica, quartz, feldspar, chlorite. "780 red granite."	
Arbose? but not rounded.	

PRECAMBRIAN.

±875
Quartz and feldspar? a pounded aplite?
Mean 890
Feldspar, chlorite, mica hornblende.
±900
Fine gr., dark feldspar, chlorite, etc
875-1000
Rusty, much mica.
"Wedged in bottom from description in gabbro."

It looks as though thus close to the Archean land mass the formations were much broken by unconformities and sandstones (of course allowance must be made for imperfect records), and perhaps the term Hermansville will be fittingly applied to the lower 50 feet of the Calciferous. We may compare the triple division of the Calciferous, with the Shakopee dolomite, New Richmond sandstone, and Oneota dolomite of Minnesota.

System	Series Name	Formation Name	Columnar Section	Thickness	Character of Rock
QUATERNARY	Pleistocene	Recent Champlain Wisconsin and earlier drift sheets		1100 – 0	Sand gravel, boulder clay Lake Superior pink clay Till: boulder clay sometimes very sandy, again clayey and dark. A gray and red till may in some places be distinguished an older and a younger
POSSIBLY LATER	Conemaugh	Woodville		110 – 0	Light reddish sandstone and sandy shales
	Pennsylvanian (Upper Pottsville)	Saginaw		400	White sandstone, coal seams, black and white shales; thin bands of limestone and of siderite, rarely broken up and found in fragments of the sandstone
		Parma		170 – 0	White sandstone and conglomerates, of small white quartz pebbles, brine and sulphates.
CARBONIFEROUS	Mississippian	Bayport or Maxville Upper Grand Rapids Upper St. Louis		255 – 50	Limestones light and bluish, cherty, also calcareous sandstones
		Michigan Lower Gd Rapids Lower St. Louis Osage or Augusta		300 –	Dark or bluish limestones and dolomites with gypsum and blue or black shales. rarely reddish or greenish shales and dark or red sandstones
		Napoleon Upper Marshall		500 to	White sandstone, often pyritic, brine or fresh water, sulphates low
		Lower Marshall		200	White and red sandstones, peanut conglomerates, sandy shales, whetstones and blue shales, mud carbonate of iron and mica in the formation generally a red shale at the top and bottom
		Coldwater Buena Vista		1000 – 500	Blue shale with nodules of carbonate of iron especially at the top sandstone, very subordinate streaks of fine grained limestone, especially on the west side, black shales at the base.
		Sunbury or Berea Berea			White sandstone, brine and salt even near the surface
DEVONIAN	Neo-Devonian	Bedford Antrim (Senecan)		480 – 100+	Shale mainly black and always at the base, with huge round balls of calcite, towards the top, blue and black shales.
	Meso-Devonian	Traverse: Naples goniatite fauna; Petosky limestone; Acervularia beds Hamilton (Erian)		660 to	Bluish limestones, dolomites and shales: base a blue or black shale: top generally limestone and rarely reddish.
		Bell and (Marcellus Shale)		50 60	
		Dundee (Ulsterian)		255 to	Limestone buff and light brown, fiercely effervescent, somewhat cherty.
	Latest Ontarian possibly Eo-Devonian	MONROE: Upper Monroe or Detroit River; Flat Rock		2.5 to 0	Dolomites, mainly, the Anderdon formation is limestone, gypsum or anhydrite also occurs, with celestite and sulphur
		Middle Monroe Sylvania		110 to 50	White sandstone very pure passing towards the north into calcareous sandstone.
	Upper Ontarian	Lower Monroe or Bass Island: Raisin River; Put-in-Bay; Tymochtee; Greenfield		200 ? 100 + 100 – 100 –	Dolomites at some levels sandy at others oolitic, often cherty At the Tymochtee and other levels shaly, anhydrite abundant in the lower parts of the salt basin, Celestite.
UPPER SILURIAN OR ONTARIAN	Middle Ontarian	SALINA ? (3, 2, 1)		960 to 0	Salt anhydrite, dolomites calcareous marls red and green, more rarely blue and black, shales.
	Lower Ontarian (Niagaran or Manitoulin)	Guelph and Niagara		600 to 270	White dolomites peculiar whiteness characteristic, often cherty, and with a little quartz sand which sometimes occurs in beds; pure limestone rare.
		Rochester Shale		35 to 0	Blue shale.
		Clinton		150 to 0	Reddish limestones and shales or iron ore.
		Medina and		100 to 0	Red shales, sometimes sandy or green shales
LOWER SILURIAN OR ORDOVICIAN	Upper Ordovician (Cincinnatian) (Hudson River)	Richmond		150 to 0	Shales, red and blue and sandy, gradual transition at base.
		Lorraine		315 to 2[illegible]	Shales blue, sometimes in streaks black, especially towards base
		Utica		80 to 50	Black shales.
	Middle Ordovician	Trenton: Galena; Platteville ?		471 to [illegible] ?	Limestone and dolomite; blue and shaly, or solid shale at base.
		St. Peter		18 to 0	White friable sandstone, or represented by red clay, residual top of underlying formation.
OZARKIAN ?	Lower Ordovician	Calciferous			

FIG. 7. GEOLOGICAL COLUMN OF MICHIGAN, FROM TRENTON UP

NOTES ON THE GEOLOGICAL SECTION OF MICHIGAN. PART II. FROM THE ST. PETERS UP.

A. C. LANE.

Introduction.

The writer has the benefit of the work of Professors A. W. Grabau and W. H. Sherzer,[1] though we are not yet in entire accord as to interpretation. Perfect accord can, however, not be expected. In preparing the column, not only the records of borings given in Volume V of our reports and the Annual Reports for 1901, 1903 and 1904 have been used, but also records of wells at Pickford, Grand Lake near Alpena, Strasburg and others yet unpublished. The second, or upper part of the Michigan rocks here described, including Ordovician and Carboniferous, has peculiar interest in many ways. In the first place it stands as the connecting link or field between the standard New York and the Mississippi Valley rocks. In the second place it has not been much disturbed. It is too much to say not at all disturbed, for there is caught in the synclinal fold of Limestone Mountain on Keweenaw Point the Niagaran, so that we are led to infer that notable disturbances took place along the line of the Great Keweenaw fault after the Niagara. There are in the Lower Peninsula also signs of slight foldings between Dundee and Ontarian and before the deposition of the coal measures (Pottsville; Lower Pennsylvanian).

But on the whole the strata lie in one vast little-disturbed *persistent* basin, in a gentle embayment of the great pre-Cambrian boss or shield which curves around them from Wisconsin on the west to Canada on the east. It is possible that at the center of this basin was continuous deposition, perhaps not always marine.

A notable feature is the general fineness of the sediments and absence of conglomerates. These latter are extremely rare. If one overlooks some perhaps autoclastic limestone calcirudites, occasional pebbles of quartz as big as peanuts and in the Marshall a few narrow, thin bands of conglomerate containing very little but quartz, he may say there are none. The wide variety of crystalline and igneous rocks which lie only a short distance northeast to northwest are practically absent until we come to the glacial till, where they are abundant. These facts seem strong grounds for believing that during all the paleozoic time this great area was neither glaciated nor violently disturbed and uplifted. We ought to have therefore in the Michigan section an ideal place, were the strata well exposed, to study those universal advances and retreats of the shore line which must have occurred as the ocean level was raised the world over by filling in of sediments, or lowered by falling in of blocks of the ocean floor. Ellsworth Huntington and others have recently suggested that the progress of the earth's history is marked

[1]See Grabau's papers in Science, 1909, No. 739, p. 356; Bull. G. S. A., 17, 567-636; 19, 540-553.

not merely by simple cycles of climate but in a more complex way by periods of fairly uniform climate and steady conditions followed by periods of rapidly alternating conditions and extremes of climate. During the relatively steady periods as Suess has remarked the continents would be base levelled, and as the products of erosion filled up the ocean, it would trespass far upon the continental areas, rising perhaps one foot in 32,500 years. This would tend to produce relatively insular, oceanic, equable warm climates. Plains of marine transgression would be added to those of peneplanation and denudation would be chemical rather than mechanical, and of fine sediments rather than coarse, and the range of land plant activity and of oxygenation relatively restricted.

The result would necessarily be chemical sediments, limestones, dolomites, perhaps salt and gypsum, with fine muds which might, like those of the Black Sea, be black.

During periods of disturbance there would be uplifts and down sinkings, the waters would be drawn off, erosion be quickened, the sediments coarser, the field for oxygenation larger, and the relative range of plant activity extended unless glaciation or desert conditions prevailed. Moreover such periods of disturbance would, Huntington suggests, be periods of extreme climates, not necessarily hotter or colder always but perhaps oscillating between one and the other, in any case tending to greater extremes as do continental climates now. Would it not also be likely that such periods would have an extra amount of volcanic disturbance and outbursts? In any case an extra large amount of land volcanics rather than submarine volcanics might be expected? It is likely that we can recognize already the broad outlines of these more steady and more unsteady periods as follows:

Relatively steady.	Relatively unsteady.
	Tertiary and Quaternary.
Jurassic and Cretaceous.	Permo Carboniferous and Triassic. (New Red).
Upper Mississippian.	
	Upper Devonian. (Old Red).
Middle Devonian.	Lower Devonian and Late Silurian.?
Niagaran.	Upper Ordovician Lorraine to Clinton.
Trenton-Utica.	
	St. Peter ss., minor.
(Ozarkian?) Calciferous.	Early Cambrian and Keweenawan.
	Palms and Goodrich.
Animikie black slate.	Possibly an oscillation below.
Kona Dolomite and Grenville Limestone.	Keewatin.

We should not assume that these periods of oscillation should be of uniform length or intensity. The unsteady period between the Trenton and Calciferous appears to be much less important than the great period terminating in the Lake Superior overlap (which in Michigan anyway may include a good part of Ulrich's Ozarkian[1] as well as the Cambrian, and perhaps the Keweenawan) during which Michigan was out of water or rent by tremendous volcanic outbursts. Nor is to be inferred that in the rise and fall of the sea level the two occur at anything like the same rate. The rise of general sea level due to erosion and sedi-

[1]Science, XXIX, 1909, p. 630.

mentation filling up the sea basin must be gradual, and not very great in range.[1] On the other hand the emergence due to great faults and dropping of the sea floor may be very rapid, in fact we should expect it to be much more so. But emergence due to accumulation of ice on the land and consequent shift of the earth's center of gravity would be slow. All these actions might well be complicated by local tiltings and readjustments. Thus we are not safe in making any a priori assumptions. Still it would seem to me slightly more natural to suppose a gradual transgression due to erosion and sedimentation, to be then followed by an epoch of rather rapid but irregular uplift or withdrawal of the sea for these regions.

An emergence sandstone will be relatively less extensive than a submergence sandstone, being replaced around the edges by an unconformity. Its transition to underlying beds is more likely to be gradual, without basal conglomerate of the same, as they were yet unconsolidated. Above it passes into deposits from rejuvenated lands, and around the margin it might lie under terrestrial, delta and fluviatile deposits, which might wash over it, as well as be terrestrial itself. Its connate water may be fresh at the margin. The sand itself being rehandled along a risen coast is more likely to be uniform in texture.

In many of these respects, as Berkey has shown, the St. Peter sandstone is a typical emergence sandstone as compared with the Lake Superior sandstone, and that is one reason why I do not think it extends into the Lake Superior basin. My remarks in Part I that the view point of one studying drillings is different from that of one studying outcrops in such a basin as Lower Michigan, must not be forgotten. The gaps due to discordances and disconformities are liable to be much greater, the emergence sandstones less at the outcrop. Both the St. Peters and the Berea I take to be emergence sandstones in Michigan, and neither of them have been recognized as outcrops though distinct in some drill records. The base of an emergence sandstone is probably a more definite datum plane than that of a submergence sandstone.

But a change of sediments need not imply a change in sea level. A change from a wet climate to a dry should make a great difference in the character of the sediments. Most natural phenomena that come in wave-like series have irregular waves of different lengths and intensities, and this is almost sure to be so when, as in the case before us, they are the result of a complex of factors. Of course if they were a simple result of changes in the shape of the earth's orbit or in the inclination of the north pole to that orbit they would be fairly regular. But if in addition to these factors, there have been cycles of change in the composition of the air, of accumulated stress in the earth's crust and of yielding thereto. we should expect to find great irregularity, some disturbances even in relatively steady times, and irregularity in the length of disturbances.

But large disturbances as Suess, Heim and Chamberlin have emphasized, should affect the sea level and register themselves the world

[1]At the rate of one foot erosion of a continent in 9,120 years found by the U. S. Geological Survey, the ocean would rise at about one-third of the rate at present, or say one foot in 32,500 years, which might determine the rate of growth of some limestone strata. The total range would also be about one-third the total erosion so that one-third of 1,000 feet would be probably its limit.

over. For instance mountain making disturbances which separate the Devonian and Carboniferous do not seem to have directly affected Michigan, but they registered themselves in the chronology by the Berea grit on the eastern side, and on the western by exposing the shales to an interval of weathering and erosion marked by a reddened zone.

I have prepared my notes on this part of the Michigan column with the especial idea of helping students of such problems as these to obtain the information they need. But while I have tried to give the facts one must be on one's guard lest I have read my interpretation into them. In many cases one may still inspect the drillings.

11. *St. Peters Sandstone.*—Outcrops of this have never been recognized in Michigan. It may have been confused with the general mass of Lake Superior sandstone. There is no lithological or paleontological fact to prevent the sandstones which we are obliged to group with the Lake Superior sandstone from being in part St. Peters, as Grabau, 1906, p. 583, suggests. In fact in view of the presence of the Trenton limestone at Limestone Point on Keweenaw Point, there is a little reason why there should be. Whether this sandstone would be an aerial land deposit as Berkey and Barrell have suggested, or marine, is another question. So, too, when we find the sandstone of the islands of Siskowit Bay, Isle Royale, seeming to be unconformable to the Keweenawan, and the Apostle Islands sandstone appearing to be an unconformable later formation than the beds of Clinton Point, Wisconsin, which Irving maps as Cambrian, the question arises as to their exact age. In many respects they remind one of the unconformable "conoplain" sand deposits of the arid west. Similar formations are also found along the east end of Lake Superior but as no trace of the Magnesian or Calciferous has yet been found beneath them anywhere the extension of the St. Peters section as a land or marine formation over the Lake Superior basin is purely hypothetical. Moreover as brought out by Berkey[1] the St. Peter seems to mark a period of emergence and to be very largely composed of wind-handled products of the beds so exposed. In some places in Minnesota it is perfectly conformable to the underlying strata. It is therefore not surprising if it does not extend so far as the beds above and below, being replaced by an unconformity between the Calciferous and Trenton. If a sandstone were found separating the calcareous beds of the Calciferous and Trenton it might be basal Trenton, but Rominger and others have described Trenton limestone beds lapping right up onto the Huronian quartzites. There is no necessity for supposing a quartz sandrock always to be present above an unconformity.

I would then recognize the St. Peter as marking an uplift exposing Potsdam and Calciferous to erosion and producing an emergence sandstone. This was followed by submergence and transgression, but on the whole emergence was dominant until the time of the beds here classed as Trenton. This Grabau would class as the base of the Middle Ordovician or Chazyan.

The greatest thickness of the St. Peter seems to be to the southwest. Just outside the state at Marinette, No. 2 well apparently gives 75 feet of it from 325-400 feet. But how rapidly it thins and how irregular it may be is shown by the fact that at Gladstone it was not distinctly recog-

[1]Bull. G. S. A., 17, pp. 229-250.

nized and across the Bay (Sec. 8, T. 39 N., R. 21 W.) reduced certainly to less than 40 feet, perhaps represented only by a red clay shale,—the weathered surface of the Calciferous dolomite. It seems to fill hollows in the eroded Calciferous quite as in Wisconsin. It occurs at Rapid River.[1] Farther east it is not known. The Pickford record is imperfect, and in the Neebish samples if present, it is indistinguishable from the Lake Superior sandstone. But as I interpret the well there are a few feet of Calciferous there and the St. Peter is absent, Trenton limestone immediately overlying the remnant of Calciferous at a depth between 186 and 205 feet. Fig. 4.

12. Trenton Limestone. Under this head have been grouped, as appears from Foster & Whitney's map, and the text by them, p. 140, Hall and others, equivalents to the Chazy, Birdseye, Black River and Trenton in its narrower sense of New York. We are thus including all the Mohawkian and the Chazy. Grabau would include all up to the Black River in his Chazyan or Middle Ordovician, and would combine the Trenton with the overlying Utica. In a general way it is what Bigsby referred to (1823, p. 195-6) as the "limestone of St. Joseph." He refers to its typical exposures on St. Joseph Island and describes and figures (Pl. 26, Fig. 5, Fig. 9) the characteristic Orthoceras fauna, and Asaphus platycephalus or A. barrandi hall and mentions the crinoids and corals. He also gives an excellent lithological description, mentioning the characteristic "Birdseye" texture, or as he calls it "knotty" texture of some parts. These exposures are described also by Hall in Foster and Whitney, Logan and Rominger (I, III, pp. 64-67, 83).

Pleading that neither at top nor bottom do our dividing lines exactly agree in time with the New York column, Grabau would suggest a local name like Escanaba. But it is entirely unlikely that the dividing lines are exactly the same at the two ends of the state, that is on the Escanaba and St. Mary's rivers where alone it has been, or can be, studied. Still less likely is it that where it was struck in deep wells at the other end of the state, at Wyandotte, Dundee, Monroe, Blissfield, Strasburg, etc., it is the same. Yet all over this vast area the upper line of change from a black shale (Utica) to limestone or dolomite is a well marked one, and of practical importance as it is the oil well driller's goal. It probably represents not very far from the same time. In fact why should not a change in sedimentation at this point be due to diastrophism involving an instantaneous or simultaneous change over a wide area, a general retreat of ocean due to a large drop in its bottom somewhere, both shallowing the sea and exposing the land to renewed erosion and so muddying the waters. Or there may have been a rainier climate tending to carry in more mud and promote vegetation. Or a volcanic outburst may have furnished at once a lot of mud and a lot of carbon dioxide[2] to stimulate plant activity. Why should not the response of vegetation to any one of these actions be more immediate than the adaptation of life to the change of environment. The change of fauna at the top of the Trenton (thus defined) into the Utica, both Rominger (p. 691) and Grabau (p. 353) find slight. The paleontologist might not draw the base of the Utica at exactly the same spot, but there is no great

[1]See records above.

[2]Compare the English volcanic Ordovician. How was the Mount Pelee outburst marked on the floor of the adjacent ocean?

faunal change anyway. To combine the Utica and Trenton in one subdivision as does Grabau is entirely inadmissable from the point of view of the practical stratigrapher and the oil man. On the other hand if the base of the Trenton overlaps the Calciferous disconformably, with the St. Peter present as a basal sandstone, no doubt the base may vary in age a good deal. I quite agree with Grabau that this Trenton time marks a great transgression. The continent was base levelled, the sea rising mechanical erosion low. There are no signs of disturbance. An abundant fauna suggests conditions favoring marine animals until the Utica.

For lithological subdivisions we may use the Wagner well, Sec. 8, T. 39 N., R. 31 W., with the help of the wells at Marinette.

Galena limestone, crystalline, granular	83
Limestone, fossiliferous 55 feet, white 8 feet dark 9 feet	72
Alternating blue and brown, crystalline, granular. With the dark base compare the Wisconsin oil rock	225
and	
Sandy limestones, "quartz" 6 ft., limestone 44 ft., quartz 1 ft., limestone 24 ft., compare quartz sandstone at Marinette at 260-275 feet	75
Wisconsin Trenton (Platteville?), blue shale and limestone....	41
Blue shale 4 ft., black limestone 14 ft., limestone 19 ft., blue shale 4 ft.[1]	

At Marinette too the sample at 290 feet and 300 feet to 325 feet are blue shaly, (Platteville) pyritiferous, and a well near Maple Ridge shows that this blue shaly base is persistent. Beneath it is a marked horizon for water. In the Neebish well (Report for 1901, p. 227; 1903, pp. 138-9) the bluish shalier base is distinct between 158 and 186 to 205 feet, but other correlations can hardly be made. I do not believe we can tell where to draw the line between the middle and upper Ordovician on Grabau's latest plan, his Chazyan, and Trentonian—Cincinnatian—Nashvillean, nor do I yet grasp just the meaning and value of such a line. It is quite clear that the Trenton as it has been used in Michigan and generally in the west corresponds closely with Clarke & Schuchert's Mohawkian, including whatever there may be of Chazy, which they subdivided into Lowville or (Birdseye) Black River and Trenton.

The section on the Escanaba river is said by Hall to be less than 75 feet, p. 144, and to include 15 feet near the top, gray, meagerly fossiliferous, p. 146. Rominger estimated it at 100 feet. But a close correlation of the various outcrops with well sections has not yet been made. Until it is, it seems well to be conservative in the matter of names[2] and while Escanaba limestone suggested by Grabau is a euphonious term, it is a question how it had best be used. My impression is that it would be better to use Trenton, the old widely used term in a broad sense and introduce the new term as applicable to some accurately defined subdivision. The triple division above suggested might perhaps be improved for paleontological purposes by transfer of a few feet. I think,

[1]By a numerical slip in the Annual Report for 1903, p. 132, it is given as 51 ft.
[2]Chamberlin, private letter, April 16, 1906.

however, that the occurrence of a sandy middle member, and especially a blue shaly lower, will be found widespread.

It may be that, as Grabau suggests, the typical New York Trenton in the narrower sense of Trenton is represented in Michigan by what we call in the column Utica black shale. Even then it would be a question whether not to drop the narrow use of Trenton and continue to use it in a broader sense nearly as equivalent of Mohawkian since it has been so widely used in that broad sense. But I do not think the facts are beyond question. The correlation of the Utica looks unquestionable. There was no uplift separating the Trenton and Utica. Why should not the marked and sharp change whether of climate or otherwise which produced the sudden change to the very bituminous non-calcareous shales have been felt from Michigan to New York?

It seems then better for the present to retain Hall's own and familiar name and correlation. If not, Bigsby's term St. Joseph would have had very strong claims for recognition as a general term, but it has been used for a Cambrian limestone in Missouri. His distinction from the Niagara or, as he called it, Manitoulin limestone "by reason of their difference in lithological character, in organic remains, and in geographical position," is very clear for his time, and the only question is as to the relation to the Calciferous, which in its dolomitic phase at least seems to be absent or nearly so on St. Joseph Island.

The Trenton limestone marks the culmination of Ordovician depression, when the land masses seem to have been fully buried far and near while at the same time conditions for animal life were very favorable. As Limestone Mountain on Keweenaw Point shows, the Trenton extended much farther than shown in Chamberlin and Salisbury's map, Volume II, Fig. 129, and probably over the whole Lake Superior region, which may also have been covered during the Niagara. The Archean island was probably buried at the end of the Lake Superior sandstone, but hardly the Archean nucleus, and all was submerged again during Trenton time. The thickness of the whole Trenton is best taken from the Wagner wells (1903, p. 134), as 271 feet including the Galena. This agrees very well with other wells along the Green Bay shore and the Wisconsin section, and the records of the Pickford and Neebish wells with the dip they indicate and the width of exposures in the St. Mary's river do not indicate that it thins much to the east. Oil wells on Manitoulin Island at Gore Bay report it 250 feet thick. I do not know any well in the lower part of the state that has gone through it, but in wells in northwestern Ohio it is said to be over 780 feet thick and in the Carmen well at Petrolia 602 feet. While called a limestone it seems in this state to be often dolomitic. Its regularity in thickness and its uniformity in character all point to relatively stable conditions. The transition upward is to a black shale which is in turn uniform in thickness. Grabau reports cases where the Utica black shale and the limestones underlying seem to be in reciprocal relation as though one replaced the other.

In this state what we call Utica seems fairly uniform in thickness, subject to error in drawing the line between that and the bluer shale, the Lorraine shale above. Grabau, however, does not seem to accept the equivalency of the Eden and Utica, but it has been supported by Ulrich and numerous others[1] and one can not doubt that they are lithologically continuous and homotaxial.

The line between the Upper (Bala and Caradoc) and Middle (Llandeilo) Ordovician is in Europe drawn just above *Coenograptus gracilis* of the Normanskill, which according to Grabau is Black River or late Chazy, i. e. somewhere in our Trenton.

13. *Utica* shale. (Eden of Ohio).

In many parts of the west geologists have consolidated all the shales over the Trenton as Hudson River, Cincinnati, or Maquoketa. In Michigan we seem easily able to separate a black shale[2] below, persistent and fairly uniform varying in thickness from 50 feet at the north to about 200 feet at the south. It does not seem to be separated by disconformity above or below, and the conditions which produced it, wide spread as they were, we may well expect to be universal in the sea in which it was formed. The correlation with the Utica or Eden of Ohio and Utica of western New York seems perfectly satisfactory. The base is well defined but the line between it and the Lorraine above is not sharp and probably not consistently drawn, and may have been sometimes carried up to the Waynsville, especially as none of the wells are represented by samples every 25 feet or less. Generally the Utica and Lorraine have been grouped together and mapped with the Richmond also as the Hudson River (Cincinnatian or Maquoketa). The Wagner and Pickford wells show the characteristic black color of the Utica and so do wells in the south part of the state, in harmony (Prosser, p. 35) with what is found in northwestern Ohio, but the Utica being a soft formation lying in a valley of the bed rock between the Trenton and Niagara limestone has not been recognized in outcrop, though it may be plentifully recognized in the drift near Newberry and Mud Lake. The very bituminous character of the Utica, together with its thickness, is matched only in the Devonian black shales (Marcellus, Genesee and Ohio) and it has not been uncommon for drillers to come up from Ohio, and starting somewhere in the Coldwater or Antrim, go down through the latter and swear they had struck the Trenton. The parallel will be:

Marshall	Coldwater (Waverly & Cuyahoga)	Antrim	Traverse	Dundee, Lower Tren
Richmond	Lorraine (Cincinnati)	Utica	Trenton	ton or Calciferous.

A cessation of the depression that marked the Trenton and a slight recession of the ocean giving a chance for some of the rivers that along the Appalachians even in Trenton time had been depositing their deltas to scatter their mud far and wide may have been enough to inaugurate this formation. Or would not a change of climate producing floods be equally effective?

14. Lorraine or Maysville. In this we must often include the Richmond as well as the Maysville, which we can not sharply separate from this or the Medina. The beds are abundantly fossiliferous, and their correlation with the "blue limestone and marls" of Cincinnati and "upper beds of the Hudson River" is attested by Hall, Winchell and Rominger.

[1]See 32nd annual report, Indian Department of Geology and Natural Resources, p. 616-617.

[2]50 (201-250) near Escanaba; also at Pickford (475-525); 75 on Manitoulin Island; South Bend, Ind. (1,400-1,585); Strasburg, Monroe county, 224; compare Dundee, 300; Nogard, 200 and Monroe (1,655?-1,735); Petrolia, Ont., (3,010-3,175); Sandusky Bull. 4 p. 19 252½.

The Wagner well shows for the blue beds 150 feet and more, the Pickford well shows 215 feet, and the breadth of the belt assigned to the Lorraine and Utica on the maps with a dip of 40 to 60 feet to the mile would indicate 350 to 450 feet. They probably thicken at first rapidly to the south, as the Cheboygan well would indicate over 343 feet, while in the Gore Bay well on Manitoulin Island between Niagara limestone and Trenton there is but 285 feet. At the south end of the state the records indicate about 600 feet[1] of shaly beds to be divided between the Utica, Lorraine, Richmond and Medina, say 200 feet Utica, 250 Lorraine,[2] 150 Richmond and Medina. The Lorraine, therefore, appears to be fairly uniform in thickness throughout the Lower Peninsula except at the extreme north end, where it may have been eroded. The fossils of the Lorraine and Utica are closely allied to those of the Trenton, and a change of climate, possibly to one of more rain, producing conditions more favorable to vegetation and to erosion and deposition of fine sediment, might well be held responsible for the change of sediments, though, since at the end of the Ordovician the Lake Superior island is said to have emerged extensively, the sea level may have begun to shoal and the land to be eroded earlier, but even in that case probably not so as to more than expose the mantle of dolomite, etc., of the Calciferous and Trenton. The shales may be due to the weathering of these limestones. The Michigan Lorraine is, like the Cincinnatian, generally full of fossils. Elsewhere Grabau reports coarser and more massive sediments. In Michigan, however, it is generally reported as shale. A close examination will reveal calcareous layers, soft and argillaceous limestones and more flaggy beds. The Cheboygan well shows largely limestone.[3] E. R. Cummings' remarks[4] on the conditions for alternate shale and limestone deposition seem just.

The line at the top is quite uncertain. I may have included beds corresponding to the Indiana Richmond.

15 and 16. Richmond and Medina transition beds. This is the period of deposition of coarser matter and residual red clays formed from limestone during a period of continental uplift. Ulrich[5] would class the Indiana Richmond with the Medina and the whole group not with the Ordovician but with that above. I do not doubt that he is right. There is, however, a convenience in grouping it closely with the shales below, since it is often lumped together with them in oil well drillings. If it is formed in a period of continental uplift we need not expect it to spread so far onto the continental shield. Except for a few (26) feet doubtfully assigned to the Upper Medina by Holt and Winchell, it has not been recognized in outcrop, nor was the characteristic red facies noted in the Pickford well. At Limestone Mountain the interval from Trenton to Niagara is not exposed but small and no Medina has been found. The Cheboygan well shows that though nearly absent along the outcrop it increases rapidly to the south, since Alden and Lane would

[1] 534 at Strasburg.

[2] 220 at South Bend (1180-1400); 320 at Strasburg, 1340-1660; 220 at Dundee, with 300 Utica; 343+? at Cheboygan.

[3] 325st:
2430-2432 Dark, ditto, not so much sand.
2432-2437 Ditto, fine.
2437-2455 Angular fragments of dark colored dolomitic limestone.
2455-2750 Dark colored, crystalline, dolomitic limestone.

[4] Indiana Report loc. sit., pp. 680-681.

[5] Science, 1909, p. 630.

assign from the beds pierced by that well about 142 feet (2265-2407) of red and green shale (perhaps with limey beds) to the Richmond and Medina. During this period Richmond to Medina and Clinton there was a relatively ample supply of iron to the sediments, as the Clinton ores (found in Wisconsin also) show. Very plainly there was also an uplift so that these beds were not to any extent deposited along the outcrop in the Upper Peninsula. The source of the iron may be looked for (1) in basaltic debris, (2) in exposure and erosion of the underlying iron-bearing formations, or (3) in a climate which at the same time furnished vegetable matter to dissolve iron and oxygen to precipitate it. I know of no facts pointing to the first explanation. For the second there are many arguments. The third explanation may also be true in part and does not necessarily mean a wet climate. Reds are quite characteristic of deserts and also of hot climates. Cummings has recently described the different horizons in southern Indiana very carefully[1] and agrees with Ulrich that the later Richmond represents the Medina, the culmination of an uplift. With this, Michigan facts are entirely in harmony.

My record of the Cheboygan well will be found in the report for 1901. Alden's notes are as follows, showing an intercalation of Clinton and Medina facies:

16	2265–2281	Dark, purplish, ferruginous material, reddish streak, smaller particles in small lenticular disks, rounded. With this is some bluish shaly material, moderately calcareous. Some particles rounded.
86	2281–2307	Fine, angular, gray, dolomitic material.
	2307–2311	Ditto, dark grayish.
	2311–2316	Ditto.
	2316–2367	Ditto.
8	2367–2375	Fine buff quartz sand.
50	2375–2407	Dark purplish, shaly material in granular particles and lenticular disks as above with blue shaly material.
	2407–2425	Bluish shale, moderately calcareous.
5	2425–2430	Fine, dark brownish sandy material. Partly quartz grains, partly dolomitic particles, highly calcareous.

At Port Rowan, Canada, well samples show 140 feet of similar red beds. From the Carmen well, Petrolia, 275 feet are reported. The Strasburg well shows 40 feet and in the Wyandotte (190?), Dundee, Monroe (140 ?), and other wells of that region near Ohio red beds at this point of the column can be identified, but what is noteworthy and significant, the records do not closely correspond. For instance at Monroe and at Toledo 685 feet, respectively 675 feet, above the Trenton is the last distinct dolomite sample, (Clinton?) with red and green shales below, whereas at Strasburg a few miles off at (1350-1884) 534 feet only above the Trenton is dolomite with a very red rock beneath it. No such rocks are clearly identified in the wells in the south-

[1] Cummings, E. R., 32nd Report Indiana Survey, 1907, pp 621 and 687.

west part of the state, and probably were never deposited. A simple explanation would be that there was some erosion of the underlying formation here as well as along the north border and that the red and the marine part of the Medina was much restricted. Grabau has suggested (compare also Barrell) that these red beds are not marine and includes the Medina as Clinton. There seems, however, to be a gradual transition from the beds below, rather than sudden uplift. Moreover why, if wholly land beds, should they be restricted to the center and lower parts of the basin? It should be quite clearly understood that if the upper limit of the top of the Ordovician is taken at the culmination of the uplift the series of red beds grouped here will probably be split. On the other hand research near the outcrop will probably show a disconformity with a sudden change of fauna and these beds more or less absent. This disconformity will be the place to draw the line.

No red beds are given in the Gore Bay section on Manitoulin Island, the record between the Trenton and the Niagara being:

89 Blue shale; perhaps Rochester or Lorraine.
1 Limestone; perhaps Clinton or Lorraine.
29 Shale; perhaps Clinton or Lorraine.
1 Limestone; perhaps Clinton or Lorraine.
A disconformity may be looked for here.
90 Blue shale, Lorraine.
75 Black shale, Utica.

(*Upper Silurian or*) *Ontarian.*

Some part of the formation just described may be Ontarian as Ulrich and Cummings have said, with whose interpretation of the facts Michigan stratigraphy is in entire harmony. But as it seems to mark an emergence with an early stage only in the submergence if indeed it is not a land formation and as in many of the records of wells we have to include it with the shale group below, I have preferred to associate with the shales below.

18 to 21. Niagaran—Lower Ontarian. The present status of the term Silurian is given very clearly by Prosser.[1] In its narrower sense it may ultimately be replaced by Ontarian for it is not convenient to use the term Upper and Lower Silurian as names of periods, as we can not subdivide conveniently by further prefixes. On the other hand if we use British terms we must have some regard for British usage, and the earlier use of Silurian still continued by Geikie included much more than Ontarian.

The term Niagaran as used in Michigan includes in mapping Clinton to Guelph, being exactly equivalent, *so far as the strata occur,* to the Niagaran of Clark and Schuchert and Grabau, the lower Ontarian. In sections it has been used also in a slightly narrower sense, not including the Clinton.

Bigsby, 1823, used the term Manitoulin limestone in an equivalent sense, giving its lithological character, organic remains and geographic position clearly, but while he, very clearly, distinguished it from the St. Joseph-Trenton limestone, and the Mackinaw (Dundee-Monroe-

[1] G. Also Nathorst, Geological Magazine, 1909.

Helderberg in its original broad sense) limestones, he did not separate it from the shaly beds immediately above and below, which are indeed far from conspicuous in the outcrop. If we use the term Manitoulin these limits may then be set to suit our convenience so long as the local equivalents of the Guelph and Lockport are not excluded. Farther field work before final delimitation of the word Manitoulin is advisable. The correlations given are mainly lithologic.

As the Trenton marks the first so the main mass of the Niagara marks the second paleozoic period of "epicontinental seas" of large transgression over the continent. The fact that Niagara is found in Limestone Mountain on Keweenaw Point near Hazel Station of the Mineral Range Railroad makes it highly probable that all of Michigan at least was covered and the freedom from land detritus makes it probable that the submergence was widespread, and whatever land left low, and erosion mainly chemical. We find the limestone (dolomite) extending with a characteristic clear but shallow water fauna far and wide, in Canada and all adjacent states. Elaborate subdivisions have never been made or mapped of the outcrops in the Upper Peninsula. Well records, however, show toward the center facies that we may parallel with the New York, Clinton, Rochester (Niagaran) shale, the Lockport limestone and the Guelph dolomite, and besides this at least one fairly persistent sandy and water bearing horizon, the Hillsboro Sandstone.

18. Clinton.

It seems to have been well into Clinton time before that part of the state where now is the Clinton outcrop was submerged. While all writers recognize that the Clinton facies exists in the Upper Peninsula, Rominger does not consider it worth dividing, and none have tried to map it separately. A. Winchell makes it but 3 feet thick. On Manitoulin Island there may be 31 feet. Hall gives, p. 154, Sturgeon Bay, this section:

	5 Light gray Niagara with *P. oblongus*	10	
Possibly Clinton	4 Thin calcareous and siliceous beds	6–10	25
	3 Shaly and mixed beds *Cytherina*	15	
Possibly Medina	2 Heavy bedded greenish calcareous and argillaceous limestone with chert nodules	6	
	1 Soft, brittle, greenish	20	

At Pickford it can not be identified. The whole interval from Trenton to Niagara limestone is given as only 265 feet, and no subdivisions of this Manitoulin were reported and only one sample kept.

The Cheboygan well, however, shows (Alden's notes; mine in report for 1901, p. 231) some 60 feet which may be placed here.

2206-2236	Fine sandy material, buff, angular, moderately calcareous.
2236-2245	Fine sand, slightly calcareous.
2245-2252	Dark grayish dolomite.
2252-2257	Greyish dolomite and bluish shaly material, mostly latter.
2257-2261	Ditto, dark, slaty, bluish.
2261-2265	Ditto.

In the southeastern part of the state nearer New York the Clinton is more surely identifiable.

The Port Rowan well shows 75 feet under the Rochester.
The Carmen well at Petrolia, 90
Newburg, near Cleveland, 100 + ?
Toledo, 160 ?
Monroe and Dundee wells, 60 ?
Strasburg near by, 130;
South Rockwood? 65. (1340-1405).
Wyandotte wells, 130 ?

Argillaceous dolomite seems to be the dominant rock. Water and gas are often struck in it under the Rochester shale. The thickness thus varies from 60 to 150 feet as in Ohio. At South Bend there are argillaceous dolomites 1180-1300. In the southwest part of the state at Dowagiac a brownish red carbonaceous limestone at the bottom (1760 feet) may represent it. At Kalamazoo is an interesting section as follows:

Argillaceous limestone, brisk effervescence, residue	40	to 2120
Dark gray dolomite, moderate effervescence	70	to 2190
Light buff dolomite, slow effervescence, clay and quartz residue	10	to 2200
Buff dolomite, slow effervescence, specky fragments	20	to 2220
Impure dolomite with quartz and iron ore	10	to 2230
Iron or ferruginous dolomite, little quartz, more clay	20	to 2250
	170	

Below is brown sandstone with quartz, angular feldspar (microcline) and calcite, which seems to be the base and the limit of the Medina in this region.

19. Rochester shale.

Above the Clinton a shale is generally identifiable in the records;[1] whether it is the Rochester shale or at times part of the Clinton may be a question.

Though persistent (with a tendency to be an argillaceous dolomite rather than a shale) it is never very thick, but usually 30 to 80 feet.

The Kalamazoo section of which there are samples, is very interesting, but lacks confirmation. There is always the possibility of misplaced samples. It may mean that this part of the state was out of water at intervals up to Guelph time, and that after the Clinton there was a minor re-emergence as at the time of the Richmond Medina beds. The succession is on a smaller scale, the same, limestone, shale and red beds. It is also worth noting that the shale is "red" in the Carmen well, Petrolia, that "red rock" occurs just above this slate at South

[1] Compare Port Rowan, Canada.......1220 or less to 1245;
Carmen, Petrolia, Canada....2380–2440;
Wallaceburg with Clinton.....1920–2035;
Wyandotte..................1860–1870;
South Rockwood............1295–1340;
Monroe....................(absent?);
Strasburg..................1100–1170;
Dundee....................1473–1503;
Kalamazoo.................2000–2040 with red sandstone on top;
Cheboygan.................2123–2206; (83)
Gore Bay, Manitoulin Island.. 46– 135 89 feet.

Rockwood (1285-1295 feet deep) near Detroit, and the Strasburg sample on top of the Clinton suggests emergence. The considerable faunal difference also points to quite a break between the Clinton and Niagara. That during the whole period Richmond and Medina to Rochester shale the ocean was relatively low is also shown by the absence of anything to represent these formations but mere remnants of Clinton in eastern Wisconsin. Toward the end of the time of the Rochester shale then, the shore line probably passed through Kalamazoo. This is the more interesting because just southwest in Illinois[1] the Clinton is usually about as thick as in Michigan, and is followed by a long break in sedimentation. Thus we may imagine that region emerging at the close of Clinton and staying so until after the Guelph, while Michigan did not emerge at Kalamazoo until after the Rochester shale and then at most during the lower part of the Lockport and Guelph time only.

The peculiar feature of this time seems to be an oscillation or tilting, the Clinton extending more to the south, the Rochester and Niagara opening up to the north, and from the time of the Richmond-Medina until after the Rochester shore lines seem to have been in Michigan, with the continental shield fairly high.

20 and 21. Lockport and Guelph Dolomites (Manitoulin).

The Lockport and Guelph have different fossils but have never been separated paleontologically in Michigan. The upper limit against the Salina or Monroe is marked only in this way, that the Guelph is peculiarly hard and peculiarly white. One cannot absolutely depend upon the presence or absence of anhydrite as a dividing line. It is convenient at times to separate off the lower, less white and uniform part as Lockport. The total thickness of the two at maximum seems fairly persistent and uniform, across the lower part of the state 350 to 270 feet.

At Wyandotte from	1510+ for 350 ft. (Orton).	
Strasburg from	800+ for 300 ft. or 370 ft.	
Monroe from	550 or 700 down to	900 or 1050, about 350 ft.
Dundee from	1193 or less to	1473, 280 and more.
Nogard from	1269 or less to	1640, about 371.
Milan from	1545 or less to	1643?
Britton from	1550 or less to	1643+ (white as sugar; Guelph water at 1600 ft, also at Blissfield).
Riga from	1165 or less to	1275+ white Guelph.
Coldwater to		2050.
Niles from	985 or less to	1145+?
Kalamazoo from	1730 or less to 2000,	270 (from 1875 to 2000 a sandstone).
Dowagiac from	1100? or 1325 to	1670, 335.
South Bend from	600? or 900 to	1180, 580 or 280.

The latter figure corresponds more closely with the southeastern part of the state and is really better, continuing up only to the top of the very white limestone, but in this part of the state the overlying beds are relatively free from salt and gypsum.

The Kalamazoo section is

White dolomite	145	1730–1875
Red sandy shale	45	1920
White sandstone	150	1970
Red sandstone	30	2000
Dark Rochester shale	80	2080

Dowagiac

Light dolomite with a little sand	175	1100–1275 1670?

At the north part of the state it appears to be thicker. The well No.

[1] Savage, Illinois Survey, Bull. No. 8, p. 108.

2 St. Ignace gives just 600 feet, and at Cheboygan (1525-2123) the figures are almost exactly the same.

Extreme whiteness of the upper part, occasional grains (1% or 2%) of sand as though wind blown in the dolomites, and occasional beds of sandstone are characteristic all over the state.

At St. Ignace we have:		At Cheboygan:
White dolomite	60	65
Water bearing sandy dolomite	15	35
Hard cherty dolomite	7	
White, somewhat sandy dolomite	196	220
Brown and mixed dolomite	232	185 (Coral beds + Wisconsin Byron)
Limestone	90	71 (Lockport?)
	600	576

It is exposed only in the Upper Peninsula. It forms the shore of Lake Michigan and Huron in a continuous ridge which rises to the north almost at the dip of the beds, which is about 50 feet to the mile, from the lake level 580 feet A. T. in somewhat less than 10 miles to an elevation of about 800 feet A. T. Here and there it outcrops and very often the soil over it is thin.

While as a whole it is dolomitic there are horizons, notably that of the Fiborn and Rex quarries which run nearly pure calcium carbonate. They probably occur in the lower part beneath the Guelph.

This and the absence of sediment and the absence of iron (for vegetation brings iron into solution) and the fact that it is succeeded by a salt series suggests that the climate was not a very rainy one.

22. Salina (or Lower Monroe).

The term Monroe was introduced by me in 1893[1] to 1895, and as at first used without definition did not include all the beds down to the Niagara. In my later and more formal definition (Volume V) I made it include practically all the Silurian above the Niagara, having found it impracticable to separate the Salina from the beds above. The difficulty still remains. The last salt bed is not always at the same horizon. According to Grabau there should be a marked hiatus and disconformity between the Niagara and the next overlying beds in Monroe county. The thickening which is rapid and very great as we go north would then be practically by addition of beds at the bottom formed during this disconformity.[2] Now comparing wells at Britton, Milan, Romulus and Wyandotte we do find an increasing thickness, and five feet of rock salt at Milan seems to be almost directly above the Niagara where, as in Wyandotte there are 275 feet of dolomites below the rock salt and above the white dolomite. The rock salt at Milan is 717 to 722 feet below the base of the Sylvania, and *may* be continuous with a bed 790 to 900 feet below it at Wyandotte 1080-1190 or 1235. Again as we go north the salt beds seem to occur higher up. Gypsum (anhydrite) certainly occurs above the Sylvania, and it is not very easy, though it may be possible, to separate off a part of the Monroe as Salina. The thicknesses given by Grabau for the Monroe below the Sylvania add up 500 feet. Salt occurs below the Sylvania usually within 450 feet.

[1]Report for 1891-2, p. 66.
[2]Bull. G. S. A., 19, p. 554.

The Salina would then be about as follows, as to thickness: Britton, 1180-1550 (370); Milan, 1025-1545 (520); Strasburg, 0-485 (485+); Trenton, 720 or 850-1341 (491); Wyandotte. 730-1510 (780); Romulus, 925-1603+ (678+); Edison, Ft. Wayne, 646+; Royal Oak, 1543-2502+ (959+); Stroh, Detroit, 1150-1815+ (665+); Goderich, Canada, 916-1517 (601+?). At Carmen well, Petrolia, there is 895 feet from the upper salt to the Niagara.

Back up to the southeast on the Cincinnati anticlinal the salt disappears. For instance at Wallaceburg (not far from Petrolia) only 320 feet of gypsiferous dolomites are reported; no salt. Nor was any struck in 1720 feet at Pt. Lambton, but at Algonac, Marine City and Courtright it was. At Sucker Creek, Anderdon township, about 4 miles E. and S. E. of Ballards Reef, Detroit River, a well which had the Sylvania, I presume, at 440 feet had no salt down to 1125 feet, though there was gypsum at 667-683 feet, and salty water at 1075-1080 feet. The six Church wells at Trenton show the exact edge of the salt producing area there as it occurs in only one of them, and the Monroe, Dundee and Britton wells do not show it. The Milan well shows five feet only.

It is difficult to tell where to draw the top of the line of the Salina in such case where no salt exists, and that is the excuse for considering the Salina as perhaps Lower Monroe. We have only lithological grounds to identify it with the New York Salina, and it is altogether unlikely that the top can be drawn consistently on such grounds. One can only go 400 feet below the Sylvania sandstone if present and then take the top of the nearest salt or gypsum bed. This gives fairly consistent results.

The Carmen well record runs between 1210 and 2105 feet as follows: Salt, 65; dolomite, 20; salt and light streaks of dolomite, 170; salt, 90; salt and dolomitic lime, 50; salt, 25; gray dolomite, 10; salt, 67; dolomite and salt, 40; salt, 138; dolomite and lime shale, 130; salt, 90 to 2105. There is usually quite a gap without salt above the lowest and largest salt beds. Compare Wyandotte, 970-1080, and the Edison, Ft. Wayne well, 1292-1400 feet. Along the St. Clair river we have numerous records given in Volume V, and the Diamond Crystal Salt Co. found in well No. 5 below 1630 feet, 30 feet to 1660, 20 feet to 1768, 10 feet to 1783, 24 feet to 1883, 10 feet to 1903, 252 to 2165, the latter probably the next to the first salt, since there is no large gap above. Between was "lime," i. e., dolomite and anhydrite.

This same big 250-foot salt bed is struck in other holes by them, and may be also the bed struck at Zug Island, S. Detroit, as reported in the Detroit Sunday Tribune at 1290-1528, but by the River Rouge Improvement Co. at 1180-1573; in Solvay No. 17 at 1400-1599, and in the Edison, Ft. Wayne well at 1445-1636 feet. (Compare Royal Oak 2115-2475.) We see a thickening away from the Cincinnati anticlinal.

How far this thickness would extend down the dip we do not know, as the formation has not been followed beyond Royal Oak. In the southwest part of the state no rock salt occurs, and all the Dundee and Niagara together do not amount to what the Upper Monroe alone is, on the east side of the state. It is possible that this part of the state, as before at the time just before the Niagara, was more elevated and more often exposed to erosion. The samples from 1490 feet to 1730 feet at Kalamazoo represent the Upper and Middle Ontarian and are dolomites with more or less anhydrite and quartz and *some red clay.* The water as illustrated by the Benton Harbor and St. Joseph analyses is very salty. The record may be summarized at Kalamazoo as follows:

Dolomite and anhydrite	40	1490-1530
Ferruginous dolomitic limestone	15	1545
A disconformity here perhaps.		
Ferruginous dolomite	25	1570
Dolomite and anhydrite	160	1730

Always a large residue, insoluble in H Cl, of anhydrite, especially at 1650 feet, quartz and red clay suggestive of disconformities and nearness to shore.

Now if this was, part of the time, shore for land southwest, we should expect to find still less at Dowagiac. I am inclined therefore now to raise the Niagara at Dowagiac even more than I did over Wright in Volume V, to wit, up to 1100 feet or 1135 feet, taking in all the light limestones. The Dowagiac Monroe would then be only 100 feet, (1000-1100) dolomite with 10 to 30% anhydrite and quartz. If so, then the Niagara would come in the white limestone at the base of the Niles well and the Monroe be between 625 feet and 985 feet.

The Bridgman, Benton Harbor and St. Joseph wells entered the Monroe without piercing through it. From Grand Rapids and Muskegon deep wells no samples were kept, and they are not of much use in this connection. The outcrops near Milwaukee—the Waubakee dolomite of Alden—Lower Helderberg of earlier writers is probably higher than Salina. At Ludington and Manistee, however, rock salt was struck, but apparently there is but one layer.

A record of a Ludington well put down by J. S. Stearns, with samples, is found in the appendix.

There is some question about omitting from this section the Dundee, generally so persistent. But it is certainly not well marked unless the Traverse has shrunk. And as we find over across the lake at Milwaukee the Traverse and Monroe (Milwaukee and Waubakee of Alden) represented, and not the Dundee or Corniferous it is more natural to suppose the Dundee absent here also.[1]

At Muskegon from 1700 feet, the base of the black shale, down to "gypsum and lime in streaks" is 650 feet. This latter point may be the top of the Salina, which would then extend from 2350 to 2627. A division between light and dark at 2100 feet would match the top of the brown sandy dolomite at Ludington? and *may* be the base of the Dundee.

At Manistee are a number of wells. Three records are given in Volume V, and many additional facts in the report for 1901, p. 235. The records run 300 to 400 feet higher than in the Stearns well just given. For instance one of the recent Peters wells, of which A. W. Farr kindly sent samples is about as follows:

[1]This is a radical change from earliest correlations.

Pleistocene drift	614	614	
Antrim black shale	346	960	Perhaps some blue; S. at 800 black.
Traverse	635	1595	At 978 caverous limestone; at 1350 bituminous limestone and gypsum; at 1375 brown; 1400 and 1425 1450, 1475, 1490, pepper and salt color and black and brown; at 1500 blue and at 1550 shale and 1595 shale and lime. There is probably about 95 feet of Bell (Marcellus) shale.
Dundee	50	1645	Brown, sandy and rusty, fiercely effervescent.
Monroe	381	2026	Not effervescent 1650; very red 1668 and 1690; chert and limestone at 1700; red 1720 and 1750; light lime 1760; red and buff 1790; buff 1830; 1860; oil and gas at 800 and 1900. Salt 1988–2026.

The irregular red and rusty character of the Dundee samples and the way it varies in the wells suggests a near shore deposit frequently interrupted by disconformities. The Canfield and Wheeler well XXXI of Volume V was continued below the record there given from 1947 to 2270, perhaps to 2500 feet, and no more salt was found, only a hard, white lime rock which, from the samples, appears to be Niagara. The top of the Monroe is between 1604 and 1705. So there is not over 242 to 343 feet of Monroe.

Of the Frankfort well no samples have been kept, but I am told that the wells were put down deep enough to have reached the Niagara (1800′-2200′) without striking rock salt and without reaching a very strong brine. The strength lessened toward the bottom. So that it is likely that this was just outside the Salina sea like Milwaukee, while Ludington and Manistee were just inside.

St. Ignace shows the marginal or desert New York Salina red and blue shale facies. These beds are (104-510) 406 feet thick; not much more than at Manistee or Ludington. The Cheboygan well showed the red and blue shale facies between 850 and 1300 with dolomite and brine below down to 1525. Above appears to be all dolomite from 360 down.

We have, therefore, good reason to believe that at the close of the Niagara or Guelph the sea level fell so that all of the southeastern portion of Michigan certainly was above it. If the salt deposits were laid down as a non-oceanic Caspian sea, we may suppose red shales like those of St. Ignace were deltas of a stream that fed it, and that it extended to the New York Salina where were other deltas from Appalachian streams. The bottom of the Salina sea should, however, have been below sea level, like the Dead Sea at present, for the following reason. We find just after Sylvania time and at the beginning of the Devonian incursions of ocean water and animals. Now the top of the Niagara below this is not less than 1200 feet at Wyandotte, and below the top of the Salina 700 or 800 feet. If then, the top of the Niagara at Wyandotte was above sea level after the Guelph, either the continent was raised something like a thousand feet, or there was warping of the crust during Salina. There was warping of the crust during the Upper Monroe, and since, but not I think enough to alter the fact that Lower Michigan has been permanently a basin. Any such large emergence of the continent should have left traces in the sediments derived therefrom, sandstones or red shales derived from residual clays. No such beds are known to me. The Salina appears to me rather the result of but slight emergence, which grew more marked but irregular during the time of formation of the top of the Monroe.

As is shown by records at Wallaceburg, Canada, Newburg near Cleveland, and the Monroe county wells, the Cincinnati anticlinal had formed and was out of water and divided the Salina sea into two probably not entirely separate basins, connected through Canada between Goderich and Petrolia, north of Wallaceburg and Port Rowan, the one the New York basin, the other the Michigan.

The earlier salt beds appear to be heavier. For fairly complete records see Wyandotte and Royal Oak in Volume V, and pp. 217-218 in the report for 1901. More recent records of the better class are of the Strasburg well, Monroe county, the Edison Co., Ft. Wayne, and the Morton Salt Co. and the Ford well down the river. The Romulus well is also of interest.

The outcrops in the Upper Peninsula which he takes to be of the Salina around St. Martins Bay, Carp River and the islands off shore are described by Rominger, I, p. 30. Gypsum, however, occurs in considerable quantity throughout the Monroe and if there were any disconformity at the top of the Niagara these beds might be later than Salina. A recent test near the Rabbits Back shows the following section:

Record of drilling on what is called "Rabbit Back Point," 3½ miles N. of St. Ignace, Mich., along the lake shore.

Soft clay	2 ft.		2 ft.	
Hard "	5		7	
Gypsum	1		8	
Gray rock (soft)	2		10	
Red " "		6 in.	10	6 in.
Gypsum		6	11	
Red rock		6	11	6
Gray " (soft)		6	12	
Red " "	2		14	
Gray " "	1		15	
Red " "	3	6	18	6
Gray " "	2	6	21	
Red " harder	5		26	
Gray " "	8	6	34	6
Red rock	1		35	6
Light red rock	1	6	37	
Red and gray rock	6		43	
Gray rock	1		44	
Red and gray rock	6		50	

Average Analysis.

Magnesium carb	14.16%
Calcium carb	68.40
Oxide of silica	10.38
Iron and aluminum	5.27
Organic matter	1.22
	99.43

I had six analyses from different places in this hole. The six analyses varied considerably in the amount of magnesium carb., one giving only 6% and another 24%, but the above is an average of the six.

From C. A. Campbell, President, Campbell Stone Co., Afton, Michigan. April 27, 1907.

A great many records report salt coming directly on top of "lime." Now this doesn't mean much, for without samples and careful observation one cannot discriminate limestone, dolomite and anhydrite (anhydrous sulphate of lime). In many cases where samples have been saved a good part of that which is reported as "lime" under the salt, is really anhydrite. But in some it appears as if salt really did lie directly on dolomite. I have thought of this possible explanation. The thickness of salt deposited shows that the basin must have been fed from without. Suppose that it was not only fed by straits from the ocean, but partially or wholly by alkali waters draining from surrounding lands. We know pretty well that in sea water of that day calcium chloride and magnesium chloride were present beside sodium chloride, as they are today, but calcium chloride was relatively much more important. Suppose to a more or less concentrated calcium chloride solution water containing sodium carbonate or sulphate like the alkali water of the western plains[1] were added. The carbonate would throw down calcium magnesium carbonate very promptly. The sulphate might throw down calcium sulphate,[2] in proper conditions. But calcium chloride is much more soluble than sodium chloride, and the replacement of calcium by sodium in the base would tend to make the chlorides less soluble. On the other hand calcium sulphate is much more soluble in sodium chloride solution than in a calcium chloride one. Thus the addition of sodium carbonate would tend to retard its deposition.[3] If then there was a good supply of sodium carbonate, the order of precipitation might be first dolomite, then salt, then anhydrite.[4]

It may be possible in this wise to determine how far this was a marine salt deposit, how far isolated. It would also imply that the ratio of sodium to chlorine in the connate sea water would be less below, as well as in the bitterns above left after the salt had been eliminated, than in the salt series itself, while desert waters (compare Bateson's analyses) are high in sodium relative to chlorine.

23. Lower Monroe. Bass Islands Series. 365-500 feet.

This is a series of dolomites with beds of oölite like those around Great Salt Lake as Sherzer has shown.[5] The cessation of salt making may simply show that the climate had so changed that there was enough of a supply of water to keep the more soluble chlorides from forming. Or there may have been some light crustal shifting opening an outlet. There is in Michigan no sign of structural break between this and the Salina.

Grabau subdivides as follows provisionally.[6]

d. Raisin River dolomite, zone of *Whitfieldella prosseri,* 200 ft.? with oölite zones one (Plum creek) 100 ft. below the top, Woolmith dolomite and oölite at top.

c. Put-in-Bay dolomite, zone of *Goniophora dubia,* 100 ft.+ *Leperditia* also.

b. Tymochtee beds? (Winchell Ohio), 100 ft.+ Relations unknown; quite likely equivalent to some other division, shaly and thin bedded.

a. Greenfield dolomites. Northern Ohio, 100 ft.+.

[1] Or that indeed of rivers like the Ottawa.
[2] Magnesium sulphate is much more soluble.
[3] Compare the use of sodium carbonate in boiler compound.
[4] For the necessary conditions see Van't Hoff Zur Bildung der Ozeanischen Salzablagerungen Part II, 1909, p. 16.
[5] Vol. VIII, Part I, pp. 46-100.
[6] Bull. G. S. A. 19, p. 554.

The fullest lithological descriptions are given in the Monroe county report by Sherzer, Volume VII, pp. 46-100. Fossil lists are given by Grabau, Bull. G. S. A. 19, pp. 545-549.

Oölite and sandy dolomites and dolomites with anhydrite which is primary, acicular or gashed dolomites in which the hollows were, as Kraus has shown for Monroe county, probably filled by (strontium sulphate) celestite, are characteristic rocks both in Monroe county and in the Upper Peninsula. A continuous series of wells at intervals of but a few miles at most have penetrated this series from the Ohio line to Pt. Huron. It outcrops and is exposed again near St. Ignace and Mackinaw City and the islands north of Beaver Island. It probably touches the Wisconsin shore near Milwaukee, and is reached by a series of deeper wells along the western side of the state. It will therefore be impracticable to give so particular an account of individual well sections from this point on. The following list of locations of the deeper wells in which the Monroe has been struck may be of service. It contains only those of which some decent record has been kept. Those towns where a number of wells are located are underscored:

Toledo, Britton, *Ann Arbor, Ypsilanti, Trenton, Wyandotte,* very many, Romulus, *Ecorse, Detroit,* Royal Oak, *Mt. Clemens,* New Baltimore, *Algonac,* Port Lambton, Ont., Cottrellville, *Marine City, St. Clair,* Courtright, Marysville, *Pt. Huron,* Harbor Beach (Sand Beach), Alpena, Grand Lake, Cheboygan, *St. Ignace, Frankfort, Manistee, Ludington,* Muskegon, Grand Rapids, Kalamazoo, Dowagiac, South Bend and Goshen, Ind., Benton Harbor, St. Joseph, Bridgman, Niles, *Constantine,* Jackson, Osseo, Hillsdale and Adrian.

As the total thickness from the base of the Sylvania down to the salt, shown in numerous sections, only runs from 337 to 400 feet at the outside, Grabau's estimates of the thickness of the subdivisions are clearly maxima. It is very often impossible to make lithological subdivisions. A bed of sand rock often occurs under the main Sylvania sand rock a short way. The Waubakee dolomite fossils in Wisconsin most suggest the list of the Raisin River and Put-in-Bay beds, and I think there is reason to believe this series more wide spread and persistent than the series above or below. The salt series below certainly does not extend so far either in Monroe county or to southwest or to north. To the southeast down in Ohio and elsewhere where the Sylvania sandstone is very thin and the overlying beds between that and the Devonian limestones gone or easily overlooked it is still persistent. The fossils reported from Milwaukee and from the Upper Peninsula by Rominger[1] are Lower Monroe rather than Upper Monroe forms.

Finally as we trace the beds from the thinner "Helderberg" or Monroe sections of Indiana toward the thicker sections, between Algonac and Alpena, the addition seems to be additions of beds above and below to a nucleus of Lower Monroe which itself remains fairly uniform in thickness. But there is this difference as we trace the section north along the Lake Michigan shore from that which happens as we go east toward the Cincinnati anticlinal. In the former case the Traverse (Hamilton) thickens, but very little is seen of the Dundee beneath—between it and the Monroe—and in fact there does not appear to be

[1]Mich. Geol. Surv., Vol. I, & III, p. 28.

much added to the Monroe itself though the section is puzzlingly irregular. The explanation would seem to be that for a good part of the marked erosion intervals between Niagara and Monroe (Waubakee or Helderberg) and again between the Monroe and the Traverse (Milwaukee or Hamilton) the east or Michigan side of Lake Michigan was out of water and the Wisconsin post Niagara uplift was fairly uniform from south to north. On the whole the south seems to have been first to emerge (since there is more Niagara at the north) and the seaward opening was to the north. The Salina sea was left to deposit salt. The recession or submergence during the Monroe may have been uniform. Whether the next emergence began sooner at north or at south one cannot tell since there is so decided an erosion unconformity.

A small percentage (1 to 5%) of sand found in the Monroe dolomites may have been wind blown from exposed beds of sand in Wisconsin.

Passing northeast we find the Lower Monroe persistent. We have at:

Milan.*		Britton.	
Shale	7–830	Gypsiferous d	50–825
Dark d	15–845	Cherty d	75–900
Cherty d	45–890	Dolomitic ss	100–1000
Blue and black d	100–990	Shale	15–1015
Blue shale	5–995	d	65–1080
d	30–1025	Dark blue at	1180
Anhydrite	75–1100	Sulphur and salt	1200
Dolomite	110–1210		
Anhydrite	90–1300		

Romulus.		Morton Well, Ecorse.		River Rouge.
Sandrock	45–545	Sandy dol	10–362	450
White lime	240–785	Cherty dol	50–412	500 ch. d.
Blue lime	10–795	Dove c. d	20–432	
White lime	75–870	Brown d	15–477	
Brown shale	12–882	Light d	15–492	
White lime	43–925	Dark	40–527	
Salt rock		Light with black spots	25–552	
		Gypsum	45–597	
	380	Oolite d	25–617	
		Blue d. and anhydrite	175–792	815
			430	365

d. or dol.=dolomite

At Port Huron the Lower Monroe is (1215-1555) 340 feet and making a considerable jump to Goderich, Canada, we find groups IV and V between the limestone group and the salt 364 feet. This persistent thickness is a strong argument to my mind that we have a complete section here and that between Monroe county and Goderich was continuous deposition. Jumping once more to Grand Lake, the Alpena Land Co.'s well, we find the limestone coming down somewhat farther and very thick. From 1220-1265 is the top of the first limestone above the salt and the salt is at 1352. But comparison with the wells at Alpena itself would suggest that this salt is not the usual first salt, nor the limestone that which replaces the Sylvania sandstone. The whole distance from the top of the Monroe to the first salt is 1087 feet.

*Note that the base of the Traverse and Antrim is 100 feet higher in Milan, but the Monroe seems to be about the same height. i. e. Britton is higher on a pre-Traverse or pre-Dundee anticlinal. The difference comes just about at the Sylvania. The same phenomenon appears comparing the Churchill well and that at Grand Lake near Alpena.

In the Cheboygan well there was no salt, but from bed rock surface at 360 feet dolomite at first gashed, then cherty to 570 ft., and then dark to 850 feet where red and blue Salina? shales began. The whole 490 feet may well be Lower Monroe. At Alpena the whole Monroe appears to be only about 713 feet, but there are discrepancies in the depth at which salt is said to occur at the different wells around Alpena that I cannot explain. They may be due to dislocations of the Monroe before the Traverse (which is more regular) was laid down. They *may* be due to erosion or non-deposition of the salt beds. The Cheboygan well is so much farther north that it ought to find the Alpena horizons 400 to 500 feet higher up. The red stuff from 800 feet down "dissolving" in water at 1050′ should correspond to the salt horizon at Alpena.

In the Grand Lake well a very cherty horizon from 700 to 1000 feet might correspond to the cherty top of the Lower Monroe much exaggerated. The distance down to the lower salt at 1284 would be not dissimilar. It would seem to correspond to Group III of the Goderich section and the 284 feet would then compare with the Churchill well, Alpena, thus:

1256 Churchill	with	1257 Grand Lake.	
1048		1000 "	"

In other words there was a pre-Traverse dip, from Alpena north, enough to counterbalance the present Traverse dip the other way, and in that direction was limestone and the open sea.

On the south side of the state, comparing east with west, the Traverse appears to be very thin with disconformities, but the white and yellow limestones and dolomites below the Dundee take a great development. In Jackson the Monroe may be (1870-2485+) over 615 feet thick and at Britton (with the Salina) 1050 feet, of which 680 is probably above the Salina. We infer as the lithological character is similar that there was more continuous deposition. In the western wells we find no limestones or Sylvania sandstones Middle or Upper Monroe until we get over to Jackson and Charlotte anyway.

To the east, then, the submergence of the Monroe was longer, the emergence at the close delayed, and as we shall see, intermittent, and a land mass formed to the south during the Upper Monroe.

24. Sylvania Sandstone. 30 to 440 feet thick as sandstone, 170 feet as limestone. This, the Middle Monroe formation, is easily described. It has been found only along the flank of the Cincinnati anticlinal as a well defined bed. It thins toward the outcrop where it is between 50 and 100 feet thick. It is thickest in a line through Milan (288 to 823, pebbly at base), Ypsilanti (440? from 760 feet), Royal Oak (269 to 1105 feet). It probably skirts the Cincinnati anticlinal rather narrowly, for it is relatively thin at Britton, Ann Arbor, Mt. Clemens, absent at New Baltimore though present at Port Lambton and Marine City, and absent at St. Clair but present at Port Huron.

Grabau and Sherzer are inclined to consider it aeolian. But the way the grains of sand occur in the dolomite or limestone as in Port Lambtion, (and in a series of records like those at Marine City, Volume V, we find it shading into the dolomites), its fairly regular variation in thickness, similar at similar situations* on the Cincinnati anticlinal, growing thicker to the line of thickness above mentioned, suggest that if they were wind transported they were water deposited. Of course, near the outcrop it may be more aeolian. Lithologically it is a pure (99%+) quartz sand of the highest grade of glass sand as white as sugar. The nearest like it of recent sands that I have found is one from Florida. Its extreme freedom from iron is not characteristic of desert sands. On the other hand it seems to have a characteristically fresher water (stronger in sulphates), than the beds below.

Grabau gives a disconformity with the beds below. This is not marked, though there are red sandy looking beds at about that horizon in a few wells (New Baltimore 1290-1300). But the disconformity above is most marked and as Grabau has pointed out a new fauna appears of puzzling affinities. The facts appear to be that in many places during the whole time between the Lower Monroe and the Middle Devonian the American continent was out of water, and the line marking this period of emergence is the well defined and generally accepted line between the Silurian and Devonian. This is true also around Milwaukee and in western Michigan. But the great basin of Lower Michigan was not lifted altogether out of water. The warping which caused the emergence lifted up the Wisconsin land mass and also the Cincinnati anticlinal and the Sylvania sandstone was formed as an emergent sandstone along a shore not altogether unlike those from Chicago around to New Buffalo today. It was partly aeolian but I suspect that most of the wind blown sand found its final resting place under the water, building a sandy shelf out from the shore.

But the emergence this time was not a mere recession of the sea level. There was an Appalachian warping and gentle folding extending clear to Michigan, for as Grabau has pointed out not only is there a disconformity of the Sylvania and overlying beds, but both together were folded and eroded before the Upper Helderberg was laid down, both around Alpena and to the south. One result of this was to permit an incursion from somewhere (judging by the thickening of the limestones off Alpena way) of the first Devonian looking fossils known, as described by Grabau. He tells me the same things come from the Saskatchewan.

It seems clear, comparing the Mt. Clemens, Wallaceburg, Port Lambton and Marine City wells with those at New Baltimore, St. Clair and Port Huron, that to the northwest the Sylvania is replaced by a series of limestones. Even around Detroit where it is described by Grabau and Sherzer fossiliferous dolomites and limestones occur immediately above it, but they are there unconformably overlapping.

Take the large group of wells at Marine City reported from samples, in Volume V. In all of them at about 1,000 to 1,100 feet down, and about 500 to 600 feet above the first salt, 300 ft. or so above a well marked gypsum bed (which may be really the most fitting place at which to draw the top of the Salina) we find from 60 to over 100 feet of sandstone, often calcareous and passing into a sandy limestone or arenaceous dolomite. The cherty character of this and the beds beneath like the top of the Lower Monroe Raisin River is plain. The same horizon is plain in New Baltimore 940-1275; St. Clair 1050-1270, and Port Huron

*Compare Dundee, 60 to 253; Morton Salt Co., 65 to 262; Solvay, 95 to 415; Wallaceburg, 100 to 1100; Port Lambton, 50 to 1250.

(where it is more clayey) to 1215. There can be hardly a doubt that this corresponds to the Goderich Group III of Hunt, and so presumably to the Sylvania and part of the Upper Monroe. It would seem therefore that in this direction away from the Cincinnati anticlinal the Sylvania which at its outcrop is pure silica and perhaps aeolian, land formed, passes into marine limestones, *which represent not only it but the interval between it and the next overlying beds* where exposed in the Sylvania (O.) quarry. As usual *passing from the outcrop the unconformities* grow less. In its limestone facies it is impossible to so surely assign it a thickness, but it seems to be about 170 feet. For instance St. Clair at 910 No. 2 or 900 No. 4 corresponds to Marine City at 770 or thereabout and New Baltimore at 815. In each case there is 270 to 290 feet which may be called Upper Monroe, dolomite, dolomite and anhydrite, and dolomitic limestone, like the 274 feet of the Upper Monroe at the salt shaft. Then comes a variable thickness it contains much (1110-1190—in one case it is 90%) quartz sand, making a total of about 420 to 380 feet. The Upper and Middle Monroe at New Baltimore are about 440 to 480 feet, at Port Huron 565 to 525 feet, at Goderich 554 feet, near Alpena (Grand Lake) they are (800 to 1000)—265, 535 and more. Now of course how much of this should be attributed to a thickened base of the Upper Monroe is a matter for farther research. The fairly uniform thickness for Middle and Upper Monroe from Lake St. Clair to Alpena suggests that there is no appreciable disconformity. So far as one can judge the Upper and Middle Monroe are absent on the west side of the state. Even around Mackinac and at Cheboygan there are no indications of them known to me.

25. Upper Monroe-Detroit River Series. (275 ft.)

This series seems to have been deposited in a long narrow trough at the very end of the Silurian at a time when most of the continent was out of water and much progress had been made toward the evolution of the Devonian forms. Just as in New York higher and higher horizons of the Eo-Devonian rest to the west on the Salina and waterlime, so in Michigan to the southeast and south higher and higher horizons of this rest on the Sylvania. But it is also true that the Corniferous or Dundee rests on various members of this. The Corniferous above is unquestioned Devonian. Below the Sylvania has been classed with the previous period by general consent. But the Sylvania has often been called Oriskany and the fossils of beds above are remarkably like Hamilton forms, while the very top of the Lucas dolomite has been generally taken to be below the Devonian.

If, with H. S. Williams, we place the base of the Devonian at the Oriskany and class the Lower Helderberg beneath as Silurian as used to be common (compare the 1892 edition of LeConte with the latest) we should then surely place the whole Monroe with the Silurian as I did originally.

But beneath the Oriskany comes the Lower Helderberg series of New York 300-400 feet* and Pennsylvania 600 feet, and in Europe stages E and F, and the relation of these to the faunas is a complex problem of paleogeography. After the Salina (all up), was there a seesaw, first the Michigan trough down (Upper Monroe) then it up and the New York Helderberg down? This is the view accepted by Grabau. Or is it

*Schuchert, Bull. G. S. A. 11 (1900) 270.

possible that at the time of the Sylvania the Michigan basin was so separated from that of New York that the two could have separate faunal developments, the New York receiving precursors of the Corniferous, Michigan of the Hamilton at the same time, while somewhere around there lingered relics of the Silurian faunas which when the old anhydrite and dolomite forming conditions returned in Michigan reestablished themselves?

On the whole the greater break and therefore the one best fitted to mark the beginning of the Devonian as well as most wide spread seems to be that above the Detroit River series. For there appears to be not merely a disconformity as between the Detroit River and the Salina but an actual unconformity so that the Detroit River beds were folded before the Dundee and Traverse were laid down, and this too in a wide spread way. Such a folding is indicated by the fact that while at Alpena there is[1] a dip of 42 feet to the mile to the southwest for the surface beds this does not seem to be the case for the lower beds of the Monroe. The salt is as deep to the north. Again along the St. Clair river in the Devonian there is an anticlinal near Port Huron where the oil wells are and the base of the Traverse (Hamilton) 515 feet deep there dips to 790 feet at St. Clair, then rises at New Baltimore to 690 feet. But the Monroe beds do not follow this fold. The salt runs more nearly on a level. Again, around Detroit in Wayne and Monroe counties, Grabau has described how the Dundee of the Devonian lies on various beds of the Monroe. For the present therefore it will be well to keep the line between the Devonian and Silurian as heretofore, but remembering that with the line so placed, a very Devonian appearing fauna already existed during the time of the Detroit River beds, and that, as in New York, between the Helderberg and the Oriskany[2] there is an unconformity and a more marked one prior to the Cobleskill Rondout, so it is with the Detroit River series, which *from a structural point of view* are thus closely allied to the Helderberg (Coeyman's Lower Pentamerus New Scotland, Becraft and Kingston beds.

Structurally, then, the Detroit River and Helderberg are analogous, but they differ widely in fossils. The subdivisions are as follows:

At the salt shaft, and near by, according to Grabau.

146
180 1. Lucas dolomite (with *Cylindrohelium profundum*) (200 feet +) with sulphur and gypsum.
326
9 c. Amherstburg dolomite (with *Panenka canadensis*) transition to Lucas 20 feet—
335
38 d. Anderdon limestone (with *idiostroma Nattressi* and a fauna like the Hamilton.)
40 50
373
47 e. Flint rock dolomite (with *Syringopora cooperi*).
50
420 150 feet+ ....
Sylvania sandstone.

[1] Report for 1901, p. 67, and Plate VII.

[2] See Grabau. Geology and Paleontology of the Schoharie Valley, p. 179, N. Y. State Museum, Bull. 92.

It is next to impossible to trace these largely paleontological subdivisions in the wells, especially the difference between Amherstburg and Anderdon. But the tendency to a dolomite top, with sulphur reduced from gypsum and anhydrite, and limestones lower down can be plainly followed. For instance we may correlate as Lucas (with Anderdon perhaps), Mt. Clemens (620-855) 235; New Baltimore (820-1040) 220; Marine City (770-880) 110; St. Clair (950-1050) 100. At Port Huron LVII (800-920), from 920 to 1150 is dolomite and bluish black argillaceous marls that remind one of Black Sea deposits, and may represent the Anderdon and Amherstburg. At the Port Huron Salt Co., four miles south (nearer Marysville and the Bunch farm) the corresponding horizon is from (835-980).

Above the undoubted Lucas, either as an extension of the base of the Dundee or as a still higher member of the Detroit River series (which it would be interesting to compare with the New York Helderberg) was an intercalation of limestone in the Lucas, which did not reach as far as New Baltimore or the Detroit River, for we find limestone sometimes just below the first thin dolomite that seems to lie directly under the Dundee. By the time we get to Alpena limestone occurs at various horizons, as the well at Grand Lake shows. There is clearly a tendency to replacement of dolomite by limestone toward the north in the direction probably of the open sea from which the strata came. The Michigan Monroe seems to have been like the Black Sea and Caspian but turned north side south.

At the close of the Monroe the state was so elevated that slight folds which occurred at the same time could be planed off and the underlying formation in numerous places from Mackinaw to Monroe county, made into a dolomite conglomerate, "calcirudite." So far as we know it remained above water during the opening stages of the Devonian Helderbergian. There is distinct reason to believe that *this* uplift was not symmetrical, a mere rise and fall of the sea strand produced perhaps by disturbances thousands of miles away like the earlier changes in Niagara time, but a tilting by which the west was more elevated than the east and a certain amount of folding took place. The Limestone Mountain fold on Keweenaw Point may have taken place this early. The Sylvania uplift seems to have been decidedly most at the south, opening up and depressing the land at the north. By the close of the Amherstburg the effect of a new uplift made itself felt in cutting off the northward connections and the conditions for formation of dolomite and anhydrite were reestablished and with them the Silurian fauna. The same disturbance that cut Michigan off once more may have opened up New York to the Helderbergian, so that while the Coeymans, New Scotland, Becraft, Port Ewen, perhaps Oriskany? and Esopus? beds were forming in New York 300 or 400 feet in all, Michigan was mainly out of water, and not until the Schoharie (Hall in Foster & Whitney, II, p. 225) did deposition begin in Michigan again that can be recognized by its fossils.

26. *Devonian* Dundee Limestone. 200 to 253 feet.

(Corniferous, Upper Helderberg, Ulsterian, Onondaga and Schoharie). This formation has been found throughout the state. Beside the wells already cited, one may call especial attention to the deep wells at Bay City, Assyria, Adrian, Hillsdale, Coldwater, Allegan, Muskegon and

Grand Rapids as adding to our information regarding this formation. Every where it is full of fossils, which have been described by Hall, Winchell, Rominger, Schuchert, Grabau and others.[1] On the east side of the state from the blue and black shales that may represent the Bell or Marcellus to the first dolomite, which seems to be generally the top of the Devonian (of course there may be a puzzling dolomite conglomerate at times) the formation can be traced persistently. It is very uniform in character, high grade limestone with only a few per cent of magnesia, not infrequently over 98% $Ca\ CO_3$, light colored, or brown with oily matter, containing a water relatively high in sulphates, relatively weak and strong in $H_2\ S$, and generally hard, sometimes, not always cherty. Beginning with an even 100 feet (at Britton—97 at Milan) thick in the southeast corner of the state it thickens slowly to Port Huron (143+), Petrolia (190), Tilbury (158), Port Rowan (250), being evidently continuous to New York. Going west and north it at first thickens until it gets its full thickness of about 250 feet as shown at Jackson, Charlotte, Assyria (1875 or 1940 to 2040+), Bay City and Alpena, then begins to thin being but 190 at Kalamazoo, 155 or more at Allegan, not over 125 at Dowagiac and Niles, very likely much less, a good part of the 125 feet being really Traverse (Hamilton) or Monroe. In northern Indiana (Goshen 60 feet, South Bend 65) it is less than 100 feet thick. The Traverse and Dundee combined shrink fast to the south and east and as the Traverse (Hamilton) is known to extend to Milwaukee while the Dundee does not, it would seem likely that the Dundee is the one that lessens.

For instance the Niles well on p. 280 of the report for 1903 may also be interpreted as having only 12 feet of Dundee and then entering the Monroe and that in Volume V as (having Oriskany at 540) having only 40′. All these wells in the southwest corner might also be interpreted as striking through from some part of the Traverse corresponding to the Alpena limestone into the Monroe, the Dundee being omitted, though against this is the occurrence of the Corniferous (Dundee) in Northern Indiana.

As we go up the Lake Michigan shore, however, by Grand Rapids, Muskegon, Ludington, Manistee and Frankfort northward it is apparent that the Traverse expands to the thick 600 foot section found in its northern outcrop while the Dundee does not increase so much. The top thirty feet and other places are sometimes quite sandy[2] and often cherty. It is not often sandy on the dividing line between it and the Monroe.[3]

Throughout my work in Volume V and the annual reports I have considered all the Dundee as a limestone and this has given consistent results. Four miles east of Mackinaw City, however, I visited in July, 1902, a section exposed by a creek where I thought I found the Dundee directly overlying magnesian limestones of the Monroe. But Grabau found in the top layers of the magnesian beds a typical Schoharie fauna, agreeing with Hall's determinations on Mackinac Island 50 years earlier.

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[1]Annual report for 1901, and Bull. G. S. A. 17, (1901) p. 719.

[2] Allegan 1275-1300 top. Bay City 2822-2852. Benton Harbor 665-700. Charlotte 2000-2250. Detroit 475 to 580? Kalamazoo 1270-1310. Manistee, 1675. East Lake 1670 or 1600-1650, Peters. Ludington 2075-2175.

[3] Farther north than Manistee no wells enable us to know surely how thick it is but 100-200 would seem to be enough at the outcrop. A Schoharie fauna 4 miles east of Mackinaw on the creek must be near the base. The top is found at the north end of Beaver Island but the other islands, Garden Island, etc., are Monroe.

We must then grant the occurrence of magnesian beds near the base of the Dundee[1]. It would be strange if overlying a magnesian formation the base were not magnesian. The paleontological and structural dividing line may be a few feet beneath the lithologic line which we have to use.

The Dundee marks a period of general return of the sea after a period of uplift. There seems to have been no great climatic change since the beginning of the Niagara. The continent must have had a mantle of limestone and chemical denudation was still dominant, animal life over vegetable. At the top of the Dundee we seem to pass without reversal of change to a series of blue or black rather than yellow beds, which seem to point to a wetter climate producing more erosion and more vegetation. There may also have been some uplift starting the streams into renewed activity. In the Hamilton are smaller reefs reminding one of the Dundee and Monroe. It is a transition group.

27. Traverse (Hamilton and Marcellus, Erian of Clarke & Schuchert, Delaware[2] of Ohio). 600 feet—

As this group is much thicker and better exposed in the north end of the state and its very existence along the south line of the state, which seems indeed to be near where at this time an old shore line afterwards was, has been doubted, we begin our description from the north, where it outcrops on Grand and Little Traverse Bays and thence frequently around to Alpena and Thunder Bay and is nearly uniform in thickness—600 feet with a basal shale (Bell shale 80 feet) which corresponds to the Marcellus and is persistent throughout the state.

Grabau gives:

Chert beds	45-50	Naples goniatite fauna at top.
Petoskey limestone.....	360	Stromatopora and buff magnesian.
Acervularia beds.......	110	Bryozoa beds.
Bell shales............	80	
	600	

Around Alpena it is practically as thick, and is found thick in Alcona county at Grayling, and at Bay City where it is thickest 660 feet.

Cooper makes the divisions here:

1. Sandy limestone............	10		This is 100 in Plate VI of V.
Calcareous sandstone........	15	25	
Blue calcareous shale.......	55	80	
Limestone, fossiliferous......	10	90	
Limestone, growing shaly...	16	106	This is 47 in Plate VI. I mistook it for Marcellus.
Blue calcareous shale.......	11	117	
2. Limestone.................	7	124	
Calcareous sandstone, brine...	46	170	
Sandy limestone............	30	200	
Dark brown sandy limestone..	50	250	
Dark gray sandy limestone brine....................	45	295	
Siliceous limestone (gypsum)..	35	330	
3. Blue calcareous shales.......	180	510	—This is probably the Acervularia beds and Bell shales.
Shaly limestone............	40	550	
Blue shale.................	50	600	
Black shale................	60	660	

[1] This appears to be also true of the base of the Columbus limestone, the equivalent of the Dundee in Ohio.
[2] Sandusky has been discarded.

At Harbor Beach it is said to be 605 feet thick, with 15 feet of hard rock 280 feet down. When we get to Port Huron nearer the Cincinnati arch it seems to have shrunk to (185-515) 330 feet or so, and thence down to the Ohio line it tends to shrink especially toward the axis. But the marked *black or blue shale base persists.* There is no notable difference in lithology. Hence *there is reason to suspect that the loss is mainly by removal of the top.* There is a fairly persistent division to which the drillers apply customary names:

Cooper's 2. Petoskey limestone. The "top lime" 85′ ± (sometimes pyritic at its top).

Cooper's 3. The "top soap rock" 150′ ±

Acervularia beds. "Middle lime" 4-15. Never thick, but persistent, the Encrinal limestone?

And Bell shales? "Bottom soap rock" 65. Darker than the other.

These beds we can follow gradually decreasing through Port Huron, Marysville, Courtwright, St. Clair, Marine City, Port Lambton, Algonac, Wallaceburg, New Baltimore (230), Royal Oak (215), Ypsilanti (229), Britton (190), Adrian (95), and Prosser's recent investigations show a few feet of Hamilton, the Delaware Limestone (30 to 40 feet) in Ohio. Now turning west we find at Jackson perhaps 55 feet (1715 to 1770) all calcareous shale, at Assyria (1810 to 1875 or 1940) 65 to 130 feet, at Charlotte 55 feet (1930-1985 ft.) or less, Kalamazoo 70 (60 ft. blue limestone, 10 ft. blue shale to 1270), Dowagiac 74, Allegan (1095-1264) 169, Benton Harbor (475-665) 190.

We see that it is thinnest near Jackson and begins to thicken again, toward Milwaukee, and that a blue or black shale base is persistent. If we go to a group of wells around Constantine and White Pigeon[1] we find irregular records and a red gritty shale at the top of the Traverse (108 feet thick) which looks like an old erosion surface. There is good reason then to suppose that during *late Hamilton* (Traverse) there was some emergence, while the line between Dundee and Traverse does not appear to be marked by a noteworthy change here in Michigan. We find also in New York the closest affiliation in deposition between Onondaga and Marcellus. The supposed unconformity at the top and maximum depression at the base of the Traverse is in harmony with the description by the Wisconsin Survey (ii. p. 397) of the beds there as early Hamilton. The paleogeographic map of the Hamilton by Schuchert should therefore probably be changed slightly, the Kankakee peninsula moved a little to the east so as to head at Jackson[2] and probably running not far north, for passing north from Benton Harbor, the Traverse thickens rapidly, is about 400 feet thick at Muskegon, and as thick as ever at Ludington (1365-1962), Manistee (980-1600) and Frankfort, with the basal shale well marked. It looks therefore as though the Hamilton sea was persistent, (the land less elevated) to the north.

28. Antrim Shale. (Senecan, Genesee?, *Portage* and Chemung? of New York, Ohio, Huron, Chagrin, Cleveland and Bedford of Ohio. 480 to 140+.

There is good reason, as we have seen, in the thinning of the formation and in the irregularity and reddening of the top, to believe in an elevation south of Michigan toward the close of the Traverse (Hamilton).

[1] Report for 1903, p. 282.
[2] Grabau Schoharie Valley, p. 232.

This does not seem to fit well with studies of some others.[1] But in Iowa, too, the Upper Devonian is said to be unconformable on the Middle.

At the base of the Antrim shales on Thunder Bay Grabau found a Naples goniatite fauna which would imply perhaps that the Antrim black shales though lithologically like the Genesee shales were really somewhat later, and the Genesee is more or less missing. Dana used to unite the Genesee with the Hamilton; Clarke and Schuchert group it as Senecan with the Portage.

This horizon is struck widely: At Bay City (thickness 315); Alma (315?); Grayling (575); Killmaster (480); Manistee (340+); Ludington (200); Muskegon (135+80 or 215); Grand Rapids (275); Charlotte (270?); St. Joseph (185 to 520—to 750=230 to 565); Allegan (480?) Assyria (375?); Kalamazoo (200+-490?); Dowagiac (483+?); White Pigeon (322), and numerous wells southeast: Jackson (240+75); Hillsdale (310 + 10) and Osseo (304? + 100?); Adrian (226 + 30B); Madison Oil Co. (225+20); Ann Arbor (140+160B); Old well 333-700 including Berea 367; Manchester Oil Co. (271+2); Pontiac (157+253B); Valley Center (272+30); Harbor Beach (456+61), and numerous wells southeast which do not show the full thickness of not less than 340 feet. In order to get consistent results and thickness it is necessary to recognize that the transition to the Berea Grit is gradual and a greater thickness of Berea Grit or strata ascribed thereto is always at the expense of the Antrim. Ulrich would transfer the Upper Devonian (Antrim) to the system above. The Antrim consists of dominant shales, black and bituminous at the bottom, then blue sometimes, and at top where it passes into the Berea Grit, or the horizon thereof red or interstratified with sandstone and gritty.

If we must put the base of the Carboniferous at the base of the Bedford we shall have to split the Antrim in a very impractical way, though we could readily enough follow Ulrich's suggestion and place it lower. Another noticeable thing is that just as the Sylvania is confined to the east side of the basin and the Cincinnati anticlinal, so is the Berea Grit, and when the Berea Grit does not appear, then the upper strata of the Antrim have a red facies like the Bedford of Ohio, or the Richmond top to the very similar Lorraine, Utica and Richmond.

This red facies[2] is, it seems to me, very likely a land or delta facies, the oxidation being due to exposure to atmospheric oxidation. Where the Berea Grit is *well* developed it is, I believe, never found. It therefore may indicate some uplift; an uplift generally taken to mark the close of the Devonian and beginning of Carboniferous. There is no question but that the Antrim would include some of the Ohio Bedford if it is present. The upper part of the Antrim is blue rather than black and frequently there are beds of sand and grit. There is generally at least 100 feet of the bottom black shale, but as there are blue and black shales alternating at times, the records may or may not show the Cleveland, Chagrin and Huron as one solid black shale, or may overlook the Cleveland and count everything down to the Huron as blue shale. At Grayling, Ludington, Bay City, Jackson, and Ann Arbor, however, con-

[1] Chamberlin. II. p. 430: Schuchert, Grabau, etc.
[2] But the Bedford is not always red. See Morse & Foerste. Journal of Geol., 1909, (XVIII) p. 166.

tinuous sets of examples were kept, and beginning at what we take to be the base of the Berea or Sunbury shale we have the following results:

Grayling No. 1.

Red and blue shale	50–1590
Dark shale	210–1800
Blue shale	100–1900
Green and black shale	100–2000
Green and blue	125–2125
Very black shale	40–2165
	365

Grayling No. 2.

Rusty at	1720
Dark	220–1980
Gray	80–2060
Black	140–2200
Gray	40–2240
Black	40–2280
	300

Bay City.

Gray and white sandstone	170–2265
Blue shale	25–2290
Black, oily[1]	80–2370
Black, with signs of limestone	120–2490
Black pyritic	90–2580
	315

Jackson.

Sandy shale	75–1475
Dark shale	5–1480
Black shale	132–1612
Blue shale	12–1624
Black shale	61–1685
Calcareous black	20–1705
Black	10–1715
	235+

Ann Arbor.

Gray sandstone	15–415
Sandy shale	25–440
Black	5–445
Gray sandy	75–520
Black and green	10–530
Gray	15–545
Black	30–575
Sandstone	5–580
Black sandy	20–600
Black	80–680

Ludington.

Blue green shale Coldwater	550–1200
Black shale	200–1400

No difference noted in samples taken every 25 feet.

Harbor Beach.

Blue	50
Black	3
Blue	133
Black	270

Alma.

Black shale	50–2300?
Blue shale	60–2360
Black shale	260–2620
	315

Manchester.

Red shale clay	2–329
Blue shale	12–341
Black shale	11–352
Blue shale	138–490
Black shale	110–600

The variability shown is that of delta, estuarine or muddy sea deposits. When a well marked Berea Grit horizon is wanting as for instance at Alma and Grayling, it must be largely guess work to draw the line at the top of the Antrim.

29. Berea Grit (or standstone[2]) 273 feet.

This is an Ohio formation and has never been seen at the surface in Michigan, but may be traced very well along the flanks of the Cincinnati anticlinal, from near Adrian[3] north. Westward it seems soon to disappear and to be spotty in occurrence.[4] Eastward it is persistent in Ohio, but thin, about 50 feet or less and may well have been continuous with its Michigan outcrops. Northeast it is continuous past Ann Arbor and Pontiac and Birmingham, Romeo, Utica and Berville to the south-

[1] Six feet of rock salt at 2304-2310? (precipitated).
[2] Compare Oneonta, Chemung and Catskill.
[3] Madison Oil Co. 450-500.
[4] Manchester Oil Co. 2 feet red clay. Osseo, Hillsdale, Jackson, etc.

east corner of Sanilac county. Thence as shown in the Huron county report[1] it may be followed continuously in a series of wells put down to tap its brine around the Thumb to Bay City, and it was also struck at Columbiaville, Flint, Morrice, Blackmar and other wells between. From Bay City it may be traced north past Standish,[2] East Tawas,[3] Oscoda,[4] and Killmaster[5] to Harrisville,[6] near which it comes to the under surface of the drift. Its thickness is usually about 100 feet, and as is well shown in Huron county, it thickens gradually from about 40 feet until it is thickest near its western margin (over 200 feet) where it disappears suddenly. It is exceptionally salt even near the surface, and the brine is unusually free from sulphates, much more so than those of the Traverse or Dundee.

It is generally fine grained, micaceous, a grindstone, and overlain by a black shale (the Berea or Sunbury shale).

Now if we take the Alma, Bay City and Caseville wells and figure from the top of the Marshall as a line of level we shall find the Berea Grit thick at Bay City and then tapering off and thinner as though found along the shore to the west of it, and in fact if we compare the whole thickness from the Marshall to the top of the Traverse we find it thinner to the west. At Grand Rapids it is 1647 as against 1615 at Alma, 1760 at Bay City, 1840 at Caseville. Hence we have the form of a deposit (see Figure 6) formed along a shore running nearly N. and S. through the center of Michigan. It is also true that it is coarser where it is thicker and not so pure, more of a fine grained grindstone, to the east.

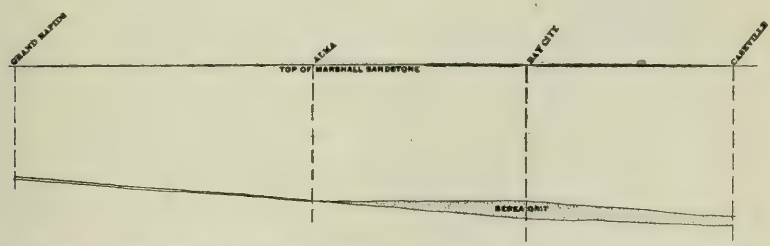

Fig. 6. Section of Berea Grit and adjacent formations from Grand Rapids to Huron county.

This would point to a marked drop in sea level which may as well be taken for the dividing line between Carboniferous and Devonian. The paleontologists are inclined to draw the line lower down. In that respect we have something like the same question that arises as to the red Richmond shales which are near or at the top of the Devonian, but there is a marked difference here in that above the Berea Grit we do not pass into limestone like the Clinton limestones, but back into black shales, like the base of the Antrim, the Berea or Sunbury shale. The conditions were this time more those of the Black sea rather than the Red sea. The extreme saltness of the brine may perhaps be accounted for in part by the erosion of the salt beds of the underlying Salina during the uplift.

[1] Vol. VII, Part 2, p. 28.
[2] Report 1901, p. 24.
[3] Volume V, Part 2, p. 57.
[4] Report for 1901, p. 70.
[5] Report for 1901, p. 66.
[6] Report for 1904.

The lowness in sulphates may also be thus accounted for. The sulphates might also be deoxidized by the associated black shales or the oil or gas often contained, but the water is not notably charged with H_2S, and we must therefore assume that there was enough iron to precipitate it as pyrite. But the hard pyritic crusts are not so characteristic as for the sulphate brines of the Traverse and Dundee below. We are inclined to believe there was originally less sulphate, and that would point to a less arid climate[1], and with that the black shales and greater abundance of mud are in agreement. At any rate the Berea Grit seems to mark an episode apart from any *great* climatic change. Competent authorities say that in following it across Ohio into New York and Pennsylvania it becomes red Catskill.

30. Coldwater shale. Part of old Waverly, Sunbury or Berea shale, plus Cuyahoga, which includes Buena Vista), plus Raccoon and part of Black Hand, perhaps; Orangeville and Sharpville? 1,000 feet.

The next series lithologically corresponds to the New York, Portage and Chemung and is one largely of shales which generally make valleys in the bed rock surface and in a state so heavily drift laden as Michigan are rarely exposed. In well drillings it must be often a matter of guess work and correlation by corresponding thicknesses and trifling distinctions to subdivide this formation. In Ohio there are two or three distinctions clearly made. The thickest, most carefully studied and best exposed section is that of Huron county,[2] as follows:

Blue and sandy shales of Willow river and Secs. 2 and 3 Huron township		172
Black Hand of Ohio? in part		
Light House Point conglomerate, Herrick's I. large fauna	4	176
Directly under should come the Racoon, Herrick's Waverly shale fauna.		
Blue shales with carbonate of iron of Port Hope, Harbor Beach, White Rock to Forestville, with *Chonetes Scitulus* cf *pulchella*, common throughout	720	896
Black Sunbury shale with *Lingula melie* and *Orbiculoidea newberryi* in Ohio	103	999
practically an even 1,000 feet.		

The black shale base is *very* persistent when the Berea comes beneath, and continues as at Alma and Grayling and Killmaster, even beyond the limits of the Berea. This is presumably the equivalent of the Sunbury or Berea black shale of Ohio and like that it is a persistent and wide spread horizon. A number of records give a few feet of red shale on top, then a few of black below (Jackson, Grand Rapids and Killmaster). The thickness is generally only 25 to 55 feet, averaging about 40, in Ohio it varies from 30 feet down to nearly nothing and may be traced clear into Kentucky. It is clear that in well records there must be some uncertainty as to whether we are dealing with red Bedford or the red top of the Sunbury in wells where the Berea Grit itself is absent. In the extreme western part of the state, as at Dowagiac and Constantine[3] (one well only) less than 20 feet of red shale has to do duty for Bedford

[1] See analyses in Clarke's Data of Geochemistry.
[2] Volume VII, part 2, pp. 18-27, 26, 247-252, Plate I.
[3] Annual report for 1903, pp. 281, 282.

to Sunbury, and the Antrim beneath is thin. I have no question that this represents a land surface, and I think the red shale is the weathered top of the lower formation. It is conceivable that the Berea Grit once extended further and has been eroded away.[1]

There has been some question as to whether it would be better to cut the Berea or Sunbury shale off from the Coldwater. But it was included in the original definition of Coldwater and has been recognized in Michigan only lithologically. It would seem best for the present to keep the term Coldwater as originally introduced to cover the interval from Berea Grit to Marshall, and use the Ohio terms Sunbury and Cuyahoga, Buena Vista and Raccoon for fitting subdivisions, so far as possible.

The Bay City section is, according to Cooper:

Top at	1290
Light blue shales	460–1750
Darker shales	50–1800
Light shales	120–1920
Red shales (salty?)	20–1940
Light shales	10–1950
Red sandy shale	10–1960
Blue shales	100–2060
Sunbury black shales	40–2100

See Vol. V (Hill's report as Salt Inspector, 1884)	1285
White shale	105
Sandy	120
Blue	20–1530
Hard limestone (probably siderite)	18
Blue shale	200
White shale	50
Black shale	35
Black limestone	65
Brine bearing sandstone	15–1913
White shale	70
Hard limestone(?)	50–2033
Sunbury?	
Soft black sand	15
Shale	25
Black oily shale	25–2100

A brine sandstone, not really at the Berea Grit level but somewhat above seems to appear at Grand Rapids 155-1205. Compare also Kalamazoo at about 710 feet. The Berea probably comes between 900′ and 1,000′. Also Dowagiac at 330 feet; Allegan at 580-615; and Charlotte at 1460-1500 may be compared. The sandy horizon at about 1920 under Bay City, somewhat brine bearing, about 200 feet above the base, may be compared with a sandstone at 1175-1200′ at Grand Rapids, and may correspond to that at Richmondville. Brine bearing sandstones in the Coldwater are also reported from Bayport, Caseville and the neighborhood of East Tawas, but correlations are largely guess work, as all of them are readily overlooked by drillers on the one hand, and none of them are thick, and sandy salty streaks are without question liable to occur at various levels. Hard streaks are also liable to occur

[1]On the whole, however, it seems more likely that while the whole period Bedford to Sunbury was one of elevation, there were two times when the shore line advanced farthest east,—one just before the Berea Grit, one just after the Sunbury shale, correlative to the Buena Vista flags. Compare Bay City 1900′–1960′ down.

which are largely bands of iron carbonate, or they may be huge round kidneys just such as are known to exist.

The outcrops of the Coldwater were described by the first Geological Survey, Hubbard, and others, by Winchell in a long series of papers[1], and by Rominger[2] who calls it and the Marshall, the Waverly Group. It covers a considerable area.

On the western side of the state the Upper Coldwater (or possibly the Lower Marshall) about 300 feet below the top or 700 feet above the bottom becomes distinctly more of a limestone.[1] At least that is one way to interpret the records at Squier's well, Bridgeton Twp. Sec. 36, 11 N., 14 W., Ludington, Muskegon, Grand Haven and Grand Rapids.

Squier's Well.

Drift to	305ft.
Limestone	55
Red sand	340
Gray sand and seams of water 2nd casing at	800
Shale to	1400

Ludington.

Drift to	576ft.
Limestone and salt water	74
Blue shale	550

Muskegon. Central Paper Co.

Lower Marshall	
Sandy shale	77
Upper Coldwater?	
Dark calcareous shale	315
Dolomitic limestone	35
Calcareous shale	185
Fossiliferous limestone	25
Lower Coldwater.	
Flags	530
	1090

Grand Haven.

Lower Marshall	
Red sandstone and clay unconformity	13
Black shale with thin limestone strata	278
Gray limestone	1
Dark shale with thin limestone strata	35
Light ditto	24
Hard blue limestone	8
Sandstone and limestone, salty water	6–358
Sand and limestone, salty water	30–388
Lower Coldwater	800?

Grand Rapids.

Sandy shale	20
Light blue shale	280
Dark dolomitic limestone	20

Alma has sandstone, black shale and limestone between 1575 and 1740, i. e. 560 feet below the top of the Marshall, corresponding to Bay City 1530′ in the well of Volume V (Atlantic Mill) 1750′ in the South Bay City well. This we may strongly suspect includes the upper part of the Coldwater down to Herrick's conglomerate 1, the Black Hand and Racoon.

In the Charlotte well from 570-680 is sandrock, from 680-1150 appearing to be shaly limestone, if the samples are representative. There are 350 feet below down to the Berea horizon. So at Jackson is a salty rock at 660 which in Volume V I took to be the Napoleon, but I am quite sure that I was mistaken. This would seem to be an appearance of the Michigan Series, or rather a Kinderhook facies and an incursion of the western Carboniferous during the Coldwater. It looks as though the eastern

[1]Biennial report 1860. See also Weeks in Bull. 191 on Marshall.
[2]Volume III, Part 1, Chapter VIII, pp. 67, 75.

side went up, the western down, at about this time (the Coldwater and Marshall) and that corresponds with what is known of the continent in a large way. This marks, it will be noticed, a shift in balance, because earlier the Berea, late Hamilton, late Monroe and early Salina unconformities are all more pronounced on the west side.

The abundance of goniatites in the sandy beach-like beds of the Lower Marshall suggests that they were open to the western ocean, and we should expect an even more Kinderhook facies in the Upper Coldwater and Lower Marshall of the western part of the state. Unfortunately there is not the slighest chance of outcrops of this calcareous Lower Marshall or Upper Coldwater, but possibly some fragments of the fauna might be identified in the drift back of Ludington.

The Coldwater gradually passes into the sandier facies of the Lower Marshall and where to draw the line is a problem not easy to settle. It will be discussed in connection with the Marshall. The Coldwater appears to be nearly as thick even if more calcareous to the west[1], the total for Lower Marshall and Coldwater being always a little over 1,000 feet.

31. Marshall Sandstone (Raccoon possibly, Black Hand and Logan of Ohio in part). 560—

This formation was extensively studied by Prof. A. Winchell who in distinction from earlier writers recognized the Carboniferous type of its fauna. When he first introduced the term (report for 1860) he made a heavy sandstone which he called the Napoleon the base of the Carboniferous, and called the beds beneath, including the Huron county grindstone quarries, the Marshall, the top of the Devonian corresponding to Chemung. Later[2] his investigations led him to include the Marshall with the Carboniferous, and then he also united the Napoleon sandstone with it as Upper Marshall, and finally concluded apparently that it was not worth separating but only a lentil. The whole matter is discussed in full in the Huron county report. The Marshall is evidently a case of emergence, micaceous sandstones becoming more and more abundant, and bands of carbonate of iron and fossils, while blue shales still persist in layers. At a number of places white sandstones occur and thin beds of what I have called peanut conglomerate, white quartz pebbles with a heavy cement of carbonate largely of iron, which weathers brown and gives the color effect of peanut candy. The transition from Coldwater is gradual, and it is not easy to fix the line consistently. In fact there are some paleontological reasons for believing that the whole southwestern Marshall may be older that the Huron county.

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[1] Grayling, Lower Marshall and Coldwater, 540-1540=1,000.
Grand Rapids, Lower Marshall, 400-1500?=1,100 about.
Muskegon, 325-1200, 1400 or 1500, about 300 Lower Marshall.
Grand Haven, 197?-1400?=1,200.
Allegan, 255-990=735?
Assyria, 320-1400=1,080.

[2] See references in Weeks Bull. 191, U. S. G. S., p. 260. But add also Am. Jour. Sci., Vol. 33, pp. 352-356, and Proc. Acad. Nat. Sci., XIV, pp. 405-430.

The Huron county section is fullest, as follows:

Napoleon (Upper Marshall) sandstone	300	300
Lower Marshall (Original Marshall)		
Hardwood Point shales and sandy flags, fossiliferous, "typical Marshall" fauna	85	385
Port Austin sandstone	23	408
Sandy shale	68	476
Point Aux Barques sandstone	18	494
Shales and flags with *Romingerina Julia*	41	535
Grindstones with bands of peanut conglomerate and broken goniatite shells	25	560

The facies with the battered shells, chip pebbles, (now coal), Solens and lamellibranchs is a real shore facies. As we go toward the center of the basin the sandy facies of the Lower Marshall seems to disappear, especially the clear white sandstone, nor is the upper sandstone so thick?

The Bay City section is, according to Cooper:

Napoleon.			
Top			850
Sandstone	20	20	
Shaly	20	40	
Coarse gray sandstone	80	120 to	970
	120		
Lower Marshall.			
Red sandstone	100	220	
Blue shale	30	250	
Red shale	20	270	
Red sandstone	20	290	
Light blue shale	45	335	
Red shale	5	340	
Red sandstone	100	440 to	1290
	320		

This may quite likely include the Coldwater down to the (Point aux Barques) Light house conglomerate, but a similarly varied section is found in the older well. In Grayling we can identify one sandstone only (440-550) and below is all plastic blue shale (with a little iron carbonate perhaps merely in kidneys occasionally) down to black Sunbury shales at 160 feet.

In Alma we have:

Napoleon white sandstone	85ft.
Lower Marshall red sandy shale	200
Red shale	20
	305

At Blackmar south of Saginaw are 245 feet of red and blue shales beneath the Upper Marshall. At Owosso and Corunna there was such a varied section that there seems to be some reason to believe that during the late Coldwater and Marshall there was not only a slight uplift, but a fold right in Michigan, between Lansing and Owosso, so that the shore may have run along in a wavy line projecting north of Lansing from Huron county to Hillsdale, while the north part of the basin was less elevated.

We find it difficult at St. Johns, Ionia and Lansing to recognize the Marshall in imperfect well records. The Charlotte well is important though peculiar in that the Bellevue limestones near by do not show. But the sandstones in it from 370 to 680 feet down (316) should almost certainly include some part of the Marshall, because their base is about 1,270 feet above the base of the Antrim, which agrees fairly with the section in Huron county (456 + 1061 = 1517, though to be sure a more exact equivalent would be the Light House conglomerate (1517-176 = 1341. Again correlation with the base of the sandstones in the Assyria well gives a dip of 14.4 feet per mile, and the dip of the base of the Antrim shale is about the same (15.6 feet per mile). Such a dip would bring the sandstones between 370 and 680 ft. to outcrop beneath the Kalamazoo valley along which the Marshall sandstone of the southern part of the state outcrops. A somewhat steeper dip of 21 feet per mile is indicated as the dip of the Antrim from Coldwater to Charlotte and such a dip would make the Charlotte well and the outcrops agree exactly.

The record of the Assyria well, 917 A. T., is as follows, which we may summarize as:

Top at		240	
Upper Marshall	80ft.		
Lower Marshall			
Calcareous blue and sandy shale	110		
Gray fine sandstone	20		
Gray sandy shale	50	180	260

Winchell originally ascribed 159 feet to the Lower Marshall.

A correlation of the deeper beds of the Assyria and Kalamazoo wells leads to dips of about 24 feet per mile for the deeper beds. The upper dips are always less so that the outcrops exposed in the Kalamazoo valley about 100 feet lower and 10 to 15 miles farther southwest, must be near the base of the section thus assigned also.

The Grand Rapids well gives a comparable thickness of sandy beds from 128 to 400 = 272 feet. The rise to Grand Haven must be 100 to 200 feet so that the corresponding strata there should be less deep. We find red sandstone 197-205; and red clay to 210, then sandstone and limestone to 600 feet, corresponding at Grand Rapids to 712. The Jackson wells are varied and not easy to interpret, but unless we imagine a fold not in harmony with the strike of the Bayport Maxville limestone at the surface, it should only include the sandstones down to 430 feet and I made an error in correlation in V.

Now how is this thinner section in the southwestern portion of the state produced? As the Marshall is an emergent formation it is easy to assume that this part of the formation emerged sooner and was more eroded, and less soon covered. The series that came after the emergence should be less complete then also, and as a matter of fact the Michigan Series here lacks gypsum and seems otherwise less complete.

But may it not be that not only did emergence but the tendency toward emergence indicated by the sandy facies begin sooner? There is a faunal indication of this.

The Marshall is well exposed in Hillsdale county, and thence by way of Allegan to the Waverly sandstone quarries near Holland. The well of Dr. S. Monroe of Grand Haven shows from 197 to 600 (403) feet of varied red, sandy, shaly and limestone beds that may be lower Marshall. The Waverly quarries near Holland gave Cooper a fauna of the Raccoon shales of Ohio and thus would correspond to the Coldwater shales below the Light house at Point aux Barques. This same fauna was found at Verona Mills, near Battle Creek, at Marshall and in Hillsdale county[1].

At Verona Mills the Battle Creek water works wells show 150 feet of water bearing sandrock beneath[2] and wells at Marshall show a similar state of affairs.[3]

Thus these beds are clearly up in the Marshall sandstone formation which can be traced in a host of wells for water all along to Huron county. Any reasonable dip indicates that they are not over 300 feet below the limestone of Bellevue (Bayport or Maxville) and most likely not over 150 feet below the top of the Marshall. Thus the total thickness for the Marshall of this part of the state of a little less than 300 feet, adding the 100 to 150 feet from the wells agrees with all we have found in the wells at Grand Rapids and elsewhere.

These beds moreover have a fauna which has not been found in Huron county, nor have the Huron county faunal zones been found in the southwest part of the state exactly. But the Light house conglomerate fauna is the same as that of Herrick's conglomerate I, and the southern Marshall fauna is, said Winchell, the same as that of the Raccoon shales directly beneath the same, and hence should be found in Huron county some 200 feet below the base of the Marshall as there delimited.

A simple and natural explanation would be that the Marshall emergence took place earlier to the southwest than to the northeast, and then the question at once arises, must we not reverse our definition of the Lower Marshall, bringing it down to include the Raccoon shales and their equivalent in Huron county, down to Port Hope nearly, adding 200 feet to the Huron county section, and making the Marshall there over 760 feet thick? This may be the future solution of the question. Cooper leans to it. But we should be as sure as possible before making changes. So we must ask what indications are there of a land mass in this direction? Also are there any indications of a shortened geological column to the top of the Marshall in this direction? To the second question the following table gives answer.

Grand Haven.		Grand Rapids.	
215	base of Marshall.	128	top of Marshall.
		420	base of Marshall.
1400	top of Antrim.	1500	top of Antrim?
		1775	
1185		1647	
567	allowance for Antrim.		
1752			

	Assyria.	Charlotte.	Jackson No. 2.	Alma.	Bay City.	Huron Co.
Top of Marshall.....	240	370	300?	1015	840	Uncon-
Base of Marshall....	500					form-
Top of Antrim........	1400					ity.
	1755	1950	1767	2640	2580	
	1515	1580	1467	1625	1740	2016

There is no thinning as compared with the center of the basin. There is a little thinning as compared with the Huron county section, but not enough, and we have besides to allow for a dropping out of Berea beds

[1] *Paleoneilo concentrica* and *attenuata* are the leading forms.
[2] Michigan Engineer, 1906, p. 136.
[3] Volume V.

and for the unusual thickness of the Huron county Upper Marshall as given in the column, which seems *very* local.

The limestone character of the western Coldwater is rather against its earlier emergence, as well as the relatively wide spread of the western Kinderhook.

There is an alternative hypothesis (supposing the paleontological facts to remain established) and that is to suppose that the Paleoneilo fauna of the Raccoon shales were immigrants northward that reached Ohio earlier but did not reach Michigan until later, until after the beginning of the Marshall. This seems to me the more likely because the fauna most like that of the southern Michigan Marshall that we find in Huron county is way up in the Lower Marshall at Flat Rock Point.

32. Michigan Series. Lower Grand Rapids. Logan or possibly absent in Ohio? (380—generally about 200.)

The Marshall is Kinderhook of the Illinois reports. Following the Marshall there was an emergence and an interval of erosion without deposition of some time around the edges of the basin, but perhaps none near the center, for the series there is of greater thickness and its deposits of gypsum attest its cut off character like the Caspian. In the Mt. Pleasant well it is 358 feet thick (1050-1408), at Midland 330 (920-1250), at Bay City 220, at the Saginaw Plate Glass Works 206 (616-820), East Saginaw 236 (398-634), and in Huron county we could make out but 197 feet. The Grand Rapids sections are also curtailed.

The Mt. Pleasant section follows and a comparison shows that it is fullest of any in the state, and that always there is a gypsum or anhydrite bed near the middle of the formation, and that with this is associated dark colored dolomites and dark blue shales. Sandstones are thin and irregular and in some cases there are dark limestones toward the base. These dark impure limestones, are quite different from the Bayport limestone. The section around the margin if at all full is something like 200 feet, but from Tuscola county south to the Assyria well are a lot of wells in which it is hard to recognize this or the Bayport at all. Occasionally, as around Byron, very salt water near the surface may indicate outliers of it. The water from the formation is salty and "bitter" full of calcium and magnesium sulphate and in that respect very different from the Marshall immediately underlying. The absence of the Michigan series from the southeastern part of the state does not seem to be wholly due to erosion at top but to uplift of the bottom, the emergence of the Marshall having progressed so far that this part of the state like the corresponding part of Ohio was out of water, and so the Michigan basin cut off, making a gypsum and dolomite precipitating sea.

Mt. Pleasant section.

Top at 1025 feet.		
Shale	5	
Sandstone	20	25
Dolomite and shale	75	100
Anhydrite and dolomite	100	200
Anhydrite	45	245
Dolomite, shale and anhydrite	103	348
Sandstone	8	356
Shale	5	361
Sandstone	4	365
Shale	15	380

The date of this emergence during which the Lower Michigan was forming in the center of the basin is pretty definitely fixed on paleogeographic grounds as that of the Upper Augusta[1] or Osage and the interval between Logan and Maxville of Ohio. The Michigan series seems to have continued forming until a depression to the west opened connection with the wide ocean at the time of the Maxville of Ohio, upper St. Louis or Kaskaski and Chester of the Mississippi Valley, this elevation during the Mississippian culminating between the upper and lower part. The section seems to be continuous without disconformity to the overlying limestone, which I have called Upper Grand Rapids, since both sets of beds were well exposed near Grand Rapids and seem in many ways bound together. The Lower Grand Rapids must then include the Lower St. Louis and probably the Keokuk and perhaps in the center strata representing part of the Burlington, the time Kinderhook-St. Louis including an era of emergence in which all of Michigan but a central sea was out of water. The exact date of the greatest withdrawal of the sea we can not exactly fix.

The dark and sometimes even black slates and the blue and dark impure dolomites, while the general association of dolomite and gypsum is like that of the Salina, give the formation a more muddy look than the Salina and one is inclined to believe that some land waste and rain erosion was still going on, though local conditions favored concentration, and after all chemical erosion and deposit was much more important in the Grand Rapids than at any time since the Traverse.

33. Maxville or Bayport Limestone, Upper Grand Rapids, Upper St. Louis, Middle Kaskaskia. (235 to 50 usually eroded).

This formation marks the culmination of a transgression which closed the time of the Michigan series. Generally it is only 50 to 75 feet thick or less, and seems to be much eroded away by a heavy erosion and uplift that took place after its formation. But in this Mt. Pleasant well there is 235 feet that may belong here, to wit:

Top at 790 feet.		
Shale and red limestone (weathered)?	30	820
White limestone	30	850
White sandstone, very salt water	120	970
White limestone	55	1025

Lithologically both these white limestones resemble the Bayport limestone, both effervescent, high grade calcium carbonate. The sandstone between might be taken as Parma. But the pebbly character of the bed above 790 feet is more that of the Parma. It may also be suggested that the white limestone and sandstone should be considered Michigan, but they are lithologically entirely unlike the Michigan elsewhere, which seems to be amply represented below. However neither the Alma nor Midland wells show any such thickness of even possibly Maxville. But the whole formation exists merely in fragments, the subsequent erosion was so heavy. Light bluish hard limestones, with chert and white sandstones are characteristic. It is the typical old subcarboniferous limestone. Faunally (with Allorisma, *Lithostrotion Canadense*, etc.) it is also closely allied with the Upper St. Louis, the middle of the Kaskaskia, and the Ohio Maxville an epoch of maximum ocean extent at this time.

[1]See Huron county report, p. 15, but see Chamberlin, II, pp. 501 4.

I do not know any good reason for not calling it Maxville.[1] Owing to the heavy subsequent erosion there is no telling how far it may have extended, but it certainly extended into Huron and Arenac counties and thence west. It also extended south of Jackson, and may once have gone over into Ohio continuously.

However in a region, from Tuscola county south around Durand, Morrice and Howell, there seems to be an area where it does not now occur and perhaps never occurred. An anticlinal uplift either prevented its formation or caused it to be eroded away. From Jackson to Grand Rapids past Bellevue and Assyria, however, there are frequent signs of its presence, though the coal measures are laid upon it with a very marked unconformity.

A detailed section at Bayport is given in the Huron county report and the following section at Grand Rapids prepared over 50 years ago by E. A. Strong for A. Winchell is of historic interest:

"Stratification at Taylor's Quarry.

Subcarboniferous Limestone—Grand Rapids.

2°	Soil—reddish with boulders	1
1°	Soil, with thin flakes of limestone Found everywhere above the limestone.	2
4′	Impure magnesian limestone, much fractured A stratum very like Nos. 3 and 5 is found in the bed of the river below the D. & M. R. R. bridge.	3
4′	Do massive, of conchoidal fracture	4
7′	Like (3)	5
2′	Shale, very soft	6
6′	Like (4)	7
2′	Shale	8
1½°	Massive lime rock	9
2′	Shale	10
1½°	Limestone—impure—'red band' Entirely local.	11
3′	Shale	12
2°	Fractured limerock	13
2′	Shale	14
3½°	Massive limestone	15
5′	Shale, dark, with Cyathophylli, &c	16
6′	Like (15)	17
2′	Like (16)	18
4½°	Massive lime rock irregularly banded with shale This stone is dark blue, blotched and veined with darker and has the appearance of the lower bed at Scribner's quarry.	19

NOTES.

"(3) and (5) are quite fossiliferous, abounding especially in Allorisma, etc. The upper surface of (4) is covered with a small conchifer. (7) is like (3) and (5) except in structure. In places it is so filled with

[1]See Michigan Miner, Dec., 1906. U. S. G. S. Water-Supply Papers. 182-183.

lamellibranchs that I have designated it the Allorisma bed. (9), (15) and (19) yield a very good lime. This stratum, spoken of at length in my notes of last year, is not found useful as a building stone. Within the compass of 40 feet it changes to an ordinary limestone. (13) resembles (3) and (5) except that fossils are rare. It has the same smooth rectangular fracture and like them, though hard when fresh, crumbles quickly upon exposure.

The above section was taken early in August, since which the rock has been penetrated to a depth of about 25 feet in stone mainly like No. 19. I have exaggerated the color in my statement above (No. 19). The stone however in the upper part is much blotched.

The measurements were made at the northeast angle of the quarry. The strata vary much in thickness, especially the shale. On the south side a mass of sandstone containing carbonaceous particles is obtruded through Nos. (19), (18), (17), (16), and (15). It cleaves away from the limestone on either side, keeping its structure quite up to the limestone. Near by a bulging mass of indurated clay is thrust up from No. (18) nearly through No. (15). The former is irregular, and does not continue across the excavation, and is usually about 2 feet in thickness; the latter is a flattened hemisphere of about 2 feet radius. So far as obtained in the neighborhood Nos. (3), (4), (5), (7) and (16) are uniform and persistent."

Winchell divided it into:

(c) Upper 10 feet
(b) Middle or red layer 5 feet
(a) Lower, arenaceous below 51 feet.

66 feet.

A thickness of 50 to 100 feet is very wide spread[1] but around Owosso and Corunna it can not be identified. At Lansing it seems to come in from 442 feet down to 477 feet at the city waterworks, 319 or 412 feet to 435 feet at the Industrial School, west in Meridian at about the same depth, at a little over 300 feet under Mason and in some of the Jackson wells, while it is cut out in others.

On the whole the climate was not one that favored the formation of shales, but limestone, chert and clean white sandstone rather, and as the continent was sinking, the rivers tended to aggrade and leave their mud before reaching the sea.

At the close of the Bayport formation the state was quite likely lifted entirely above water for quite a while, since wells in the center of the basin as near to each other as Alma, Mt. Pleasant and Midland show very different sections, and the Parma conglomerate base of the coal measures appears sometimes at one level, sometimes at another. The Bayport is apparently entirely gone at Alma.

This then would be the line between the Mississippian and Pennsylvanian, in this state the strongest disconformity since that at the base of the Devonian, and the first time that there is any evidence that the whole of the state was above water.

34. Parma Conglomerate. Pennsylvanian, Pottsville (170 feet—) (basal member).

[1]Saginaw Plate Glass Works, 75 to 81; East Saginaw, 65; Bay City, 70-80.

The recurrence of deposits in Michigan is marked by a bed of conglomerate. The pebbles are not always present and are rather small and very white, about like split peas, and the mass of the formation is sandstone.[1] The name is taken from a point on the margin of the basin which is very likely contemporary with shales, etc., in the center. As a term then, it is, like the Potsdam, not to be taken as of definite age but as the underlying basemental and shoreward facies of the Saginaw formation. As a very persistent horizon easily recognized by the pebbles which are rare in the Michigan column and as an economically important water bearer it deserves a place in the column. Compared with the Marshall brine beneath it has less of the earthy chlorides, more of the sulphates.

The wells of the Saginaw Plate Glass Works have a set of samples which show the characteristic Parma and the strata above and below and are given in an appendix.

35. Saginaw Formation. Upper Pottsville. (400).

This is the coal bearing series of Michigan. All the other formations seem actually to dip and occur deeper at the center than at the margin of the basin. Mr. Barnes, chief driller of the consolidated Coal Co., thinks that the marginal coal seams, at Sebewaing and Jackson, correspond to the deepest seam at the middle. I am hardly inclined to think it. Their chemical character is more like upper central seams and the fauna and flora of the upper seams at the center and the flora at the margin seem similar. No indications have been found of any fauna or flora later than the Pottsville, the age of anthracite coal in Pennsylvania, but a large part of the area is unknown. The series is a succession of white shales (so-called fire clays) or sandstones, black shales (called slate) and coal; and blue shales, with occasional thin bands of black band ore (siderite), and nodules of the same containing zinc blende and iron pyrites, and very rarely limestones with marine fossils[2]. More commonly, but still rarely, in the black shales a *Lingula carbonaria* or *mytiloides*, and at Grand Ledge a little pelecypod like Anthracosia occur, and this Lingula seems to mark a definite horizon, that of the Upper Verne, the two Verne coals often occurring close together and sometimes having a limestone between. The complete flora and fauna which I take to belong to the Verne is as follows: (D. White).

Upper Verne Roof.

Lingula (carbonaria or*) mytiloides.*
Anthracosia or *Macrodon carbonaria.*
Lepidodendron aculeatum (early) like *obovatum.*
" *lycopodioides* and *obovatum.*
Lepidostrobus variabilis.
Neuropteris n. s. (near *desorii) flexuosa*, and one like *harrisi* or *rarinervis.*
Sphenophyllum cuneifolium Grand Ledge.
emarginatum.

[1]Still Mr. Barnes tells me this pebble facies is pretty persistent all over Saginaw Bay and Tuscola counties, but it seems to also occur in Lansing in the body of the coal formation.
[2]Vol. III, Part 2, pp. 42, 43, 96, 203; Report for 1907, p. 19; Report for 1905, pp. 185, 188.

Cordaites borassifolius.
Cardiocarpon cuyahoga.
Diplothmema.
Mariopteris? muricata.
Lepidodendron clypeatum, Jackson.
Pseudopecopteris cf. *aroldensis* Star sp.
Sphenopteris (Crossotheca) n. sp.
P. Sphenopteris (Palmatopteris?) sp.
Pecopteris dentata.
Calamites ramosus.
Bothrodendron minutifolium.
Stigmaria verrucosa.
Heterangium.
Letter D. White, Jan. 24, 1905.

Lower Verne Roof.

Lingula
Orbiculoidea (Discina).
Productus Prattenanus.
Productus muricatus.
Avicula acosta.
Pleurophora oblongus.
Nucula ventricosa.
Trepospira sphaerulata.
Orthoceras rushense.
Nautiloid.
Fish.

This is Upper Pottsville (Beaver or Kanawha) near Mercer, compare the Kanawha Black Flint, Mercer limestone and Stockton coal, and is also near the top of the Saginaw formation. How much lower the base may possibly go we have no means of knowing. But there is reason to believe that there was not continuous deposition even in the center of the basin, and the Upper Pottsville is over 1,200 ft. thick in West Virginia.

As a whole the formation is composed of beds of rather rapidly varying thickness and character. This is true also of the coal seams. In one mine they will rise and fall 20 feet and more, pinch out or pass into black shale. A curious feature is a local persistence of facies. That is, in one township there will be a great deal of sandstone at many levels, at another there will be much shale at all levels, in one region many of the coals will be prominent, in another none. Finding a good upper coal is by no means a sign that the coals below will be extra thin.

This points to a certain persistence of geographic condition. If a big sand dune or sand bar occurred in a point flanked by a peat swamp on one side and muddy clay depositing waters on the other, while it extended more or less widely and shifted a little from time to time, yet it tended to remain in the same general region, and even built up as the general level of the water rose. We can see that this might be so by watching the effect of rises and falls in the level of the Great Lakes. A rise of 7 feet may not seriously shift the location of a swamp and the barrier beach that cuts it off from the main lake.

The writer made a list of some seven coal horizons, to which Cooper has added seven more, making the complete list as follows: Reese coal? Unionville? Salzburg Rider, Salzburg Coal, Upper Rider, Upper Verne Coal with Lingula shale roof, Lower Verne Rider, Lower Verne Coal, Middle Rider, Saginaw Coal, Lower Rider, Lower Coal, Bangor Coal, Bangor Rider.

When we consider that the whole 14 occur within 400 feet, most of them too thin to work, and that one seam may vary 20 ft. or so in elevation and thickness in a couple of hundred feet, but little stress can be laid on any such series. The Verne bunch are, however, at a fossiliferous (Mercer) horizon often quite close together, showing as a 7 to 8 foot wall with partings, (Compare the Stockton coal) and it is curious that White gives 13 horizons in the W. Virginia Upper Pottsville.

I have an idea that they have a drowned river valley effect, on the southeast side of the basin, the longest axes of the coal running northwesterly in a very irregular way, but the general shore line trending southwesterly from Huron county, something like the Carolina shore south of Hatteras turned around.

Possibly Permo Carboniferous?

36. Woodville sandstone. 110 (Conemaugh?)

Winchell separated off above the coal measures a sandstone he called the Woodville 79 feet thick. It was named from the exposure at Woodville near Jackson.

Now at Maple Rapids, St. Johns, Ionia, and Gladwin[1], we find a brown or reddish sandstone. This is not a normal color for a coal measure sandstone. It may be that this reddening is an effect of weather, but I think not and we may as well call it Woodville until we know the Woodville does not represent it. Ionia would be a much better name and is in commercial use. The Woodville exposure is not red but buff. Still it is weathered, friable and over 40 feet thick. From the way these red beds occur in some wells but not in others near by in the Saginaw Valley, we may be pretty sure that they are unconformable to the series below. I suspect, therefore, that it is not Allegheny but at earliest Conemaugh, some land formed deposit of the late Carboniferous (Pennsylvanian) or early Permian. No fossils are known. The red formations seem to be more abundant in the western part of the state and that part is heavily covered with drift. And then the redness may be a purely secondary oxidation.

During the rest of the Paleozoic, the Mesozoic and the Tertiary, Michigan was, so far as known, out of water, though there is reason to believe that at the time of the Cretaceous the sea reached nearly or quite to it, and it was nearly worn down to base level. At some time everything from Niagara to Keweenawan around Lake Superior, was levelled off, and even the harder felsites and granites did not rise more than four or five hundred feet above the general level. As we find fragments of upper Cretaceous not far off in Minnesota on the Mesabi Range and westward (Dakota and Colorado) we are inclined to put the culmination of this period of levelling at that time.

On the other hand, deeply incised valleys and caves in the limestone

[1]Vol. VIII, Part 2, pp. 158, 159. 164, 166. 195, 196. 197.

suggest a period of high level in the Tertiary between that time and the ice age. Some time someone may find in the prosecution of the limestone quarrying, around Fiborn or Alpena or Monroe in the caves upon which one comes, vestiges of Tertiary cave life.

37. Pleistocene and Recent Deposits. 1110-0.

Michigan is so near the center of the latest glaciation and that was geologically so recent, the effects of ice blocking the St. Lawrence valley having lingered so far as one can judge until within a few thousand years, that it does not seem sensible to divide the glacial and Pleistocene from the present. Mammoth and mastodon bones are found within a few inches of the surface and where forest clad the topographic forms left by the ice are almost as sharp as when left, with much less alteration than 50 years of farming will make. However, beds of peat 30 or 40 feet[1] thick, of boglime[2], lacustrine and alluvial clays[3] 14 feet thick and perhaps more, have accumulated and formations like the delta of the St. Clair flats[4] and Tawas Point[5]. So far as we can estimate[6] none of these post glacial deposits need have taken over a fraction of 10,000 years.

The greatest thickness of these Pleistocene deposits we may estimate to be 1,110 feet near the N. line of Osceola county, S. E. of Cadillac. But the greatest thickness actually measured is in the deep wells near by on the Lake Michigan shore at Manistee and Ludington, where the rock surface is below sea level. The Canfield & Wheeler well is the deepest, with the drift section as follows:

(Perhaps due to present lake) Lacustrine.		
Sand with gravel streaks	95	95
Reddish gray clay	2	97
Due to early lakes?		
Sand	105	202
Probably till, Late Wisconsin		
Gray clay	94	296
Interglacial, compare Lake Superior clays		
Dark reddish clay	2	298
Quicksand	3	301
All shades of clay, some sand	54	355
Gravel	3	358
From the Keewatin center?		
Till (clay, sand and gravel)	36	394
Reddish clay, gravel and some sand	181	575
Ground moraine of local material		
Dark clay and gravel	5	580
Dark shaly stuff	15	595
Light shaly stuff	7	602
Shale and gravel	113	715

There are indications of the various ice sheets elsewhere found[7] but

[1]Davis on Peat, Report for 1906, p. 156, etc.
[2]Vol. VIII, Part 2, p. 179 and elsewhere; Report for 1903, pp. 86-88.
[3]Vol. VIII, Part 1, p. 48; Report for 1903, pp. 93-94.
[4]Vol. IX, Part 1; Report for 1907, p. 133.
[5]Report for 1903, p. 303.
[6]Report for 1907, p. 135.
[7]See Leverett on the Ann Arbor Folio; Cooper, report for 1905, pp. 340-342; Report for 1904, p. 167; Report for 1907.

they can hardly be separated systematically, in a geological column. Both in the character of the pebbles, however, and in other ways, a transportation from the northwest as well as the northeast is plainly indicated, and at least one period between the two during which red lake clays were in some places laid down[1].

APPENDIX.

RECENT IMPORTANT WELL RECORDS.

Record of drilling on N. W. 1/4 of N. E. 1/4, Sec. 36, T. 25 N., R. 2 W., on which the Campbell Stone Co. is now operating at Afton, Cheboygan Co., Michigan.

Clay, sand and broken rock	4	4
Light colored rock	38	42
Brown rock, soft	6	48
Light rock, hard	6	54
Dark rock, soft	1	55
Dark rock, hard	1	56
Blue shale, soft	5	61
Black rock, hard	1	62
Light rock, soft	2	64
Black rock, hard	1	65
Light rock, soft	1	66
Mixed dark and light rock, hard	13	79
Light rock, hard	4	83
Gray rock, hard	5	88
Mixed dark and light rock, hard	7	95
Black rock, hard	5	100

Average analysis from 4 feet to 42 feet.

Calcium carb.	96.52%
Magnesium carb.	.90
Oxide of silica	2.10
Iron and alumina	.34
Organic	.08
	99.94

Analysis made upon every 2 feet up to 42 feet in depth varied from 95% to 97.40% Cal. Carb.; the above is the average. From 42′ to 100′ it contained from 6% to 9% magnesium carb. and from 3% to 5% oxide of silica, reducing the cal. carb. in proportion. The other holes put down on this property are practically the same and showed no difference in analysis. The 5 feet of blue shale was remarkably good, giving 68% oxide of silica and 18% aluminum and iron.

[1]Report for 1906, Russell on Surface Geology, pp. 42, 73; Rominger, Volume I, Part 3, p. 17.

From C. A. Campbell, President,
Campbell Stone Co.,
Afton, Michigan.

April 27, 1907.

Record of drilling on S. W. 1/4 of S. E. 1/4 Sec. 19, T. 53 N., R. 1 W., Cheboygan Co., Mich.

Surface	2 ft.		2 ft.	
Light colored rock	5		7	
Light colored rock	8	6 in.	15 ft.	6 in.
White coral rock	1	6	17	
Light rock	4		21	
White coral rock	2	6	23	6
Light rock	2		25	6
White coral rock		6	26	
Light rock	4	6	30	6
Dark rock	2		32	6
Light rock	6	6	39	
Dark rock	1		40	
Blue shale	8	6	48	6
Gray shale	2		50	6

Average analysis from 2 ft. to 30 ft. 6 in.

Calcium carb	94.20%
Mag. carb	1.80
Iron and Alum	.38
Oxide of silica	3.40
	99.78

The above is a fair sample of drillings on S. W. 1/4 of N. E. 1/4, Sec. 25, R. 35 N., R. 2 W., also on N. W. 1/4 of S. W. 1/4, Sec. 13, T. 34 N., R. 2 W., and N. W. 1/4 of S. W. 1/4 of same section.

CARMEN WELL, PETROLIA.

Surface clay		90
Hamilton.		
Streaks lime and shale (my Traverse) at St. Clair 775	240	330
Corniferous lime (streaks brown)	190	520
At St. Clair about 900.		
Onondaga (my Monroe)	690	1210
At St. Clair about 1630.		
Gray and Black Dolomite (Salina)		
Salt	65	1275
Dol.	20	1295
Salt and light streaks dol.	170	1465
Salt	90	1555
Salt and dol. lime	50	1605
Salt	25	1630
Gray dolomite	10	1640
Salt	67	1707
Dol. and salt	40	1747
Salt	138	1885
Dol. and lime shale	130	2015
Salt	90	2105
	895	2105

Guelph and Niagara lime	275	2380
Niagara shale (red and dark)	60	2440
Clinton	90	2530
Red Medina	275	2805
Hudson River shales (light)	205	3010
Utica (dark)	165	3175
Trenton (Trenton, Birdseye and Chazy)	602	3777

1015 ft. 6¼ in. casing, no salt water or pressure of any kind found in Trenton. Finished Dec., 1900.

Alpena Land Company well No. 1, at Grand Lake, near Alpena.

Devonian		
Bell shale	50	50
Cf. Carmen 330 P. H. 5.601		
Dundee crinoidal and fossiliferous limestone, bituminous and pyritic	215	265
Silurian		
Cf. Carmen well 520 P. H. 5.710		
Goderich group 2.		
Monroe		
Mixed samples of dolomite and limestone	30	295
Lucas		
Stylolitic limestone	15	310
Amherstburg		
Blue and buff dolomite	70	380
Anderdon limestone.		
Brown limestone	55	435
Dolomite and lime	15	450
Limestone	85	535
Compare Goderich group III.		
Black shale mixing with sample below, and limestone. Cf. Milan 830	80	615
Limestone, often crinoidal	85	700
Sylvania horizon. Cf. Milan 845–890		
Cherty, crinoidal limestone	100	800
Largely chert	30	830
Cherty limestone	170	1000

Water Analysis I.

Gashed dolomite and limestone	20	1020
Limestone, sometimes deep brown (dolomite too)	85	1105
Bluish dolomite, often gashed, with a few grains of sand	25	1130
Limestone, with a little sand, brown at top, then yellow	130	1260

Water Analysis II.

Water at 1257 feet.

Dolomite, Cf. Carmen 1210	24	1284

Top of salt formation or Salina, just about 450 feet below the cherty crinoidal limestone horizon that can not be far from the Sylvania horizon. Compare Goderich groups IV and V.

1—Salt	6	1290
Brown dolomite	50	1340
2—Salt and dolomite	7	1347
Hard layer	5	1352
3 Dark salt	5	1357
Salt, very clear from 1360–1395	80	1437
Anhydrite	28	1465
Reddish sand, marl or anhydrite	5	1470
4 Salt (Top eight feet reddish)	40	1510
Salt and anhydrite?	4	1514
Brown salt	14	1528
Salt and shale	5	1533
Dolomite, anhydrite and shale	19	1552

5	Salt and anhydrite	20	1572
	Salt, clear	17	1589
	Impure salt with shale and anhydrite	5	1594
	Salt, mainly clean, white	57	1651
	Salt with clay and anhydrite streaks at 1655–1678 Cf. Carmen well 2105.	50	1701
	Anhydrite and dolomite	11	1712

Record of Taber Well at GRAND LEDGE, furnished by W. D. Southworth. January 1908.

First	75	feet	sandstone.
Next	2.5	"	coal.
At	77.5	"	struck sand rock.
"	110	"	fresh water vein, in sand rock.
"	287	"	struck large vein fresh water, still in sand rock.
"	300	"	struck chalk rock.
"	303	"	struck shale rock.
"	385	"	struck mineral water.
"	512	"	struck brown rock. Bottom of well.

Record of well at foot of Harrison street, ½ mile down the river from the above Taber Well.

Sand rock	6	feet.
Fire clay	9–15	"
Shale slate	5–20	"
Coal	1–21	"
Slate	9–30	"
Slate and soapstone	18–48	"
Sand rock	59–107	"

A record of a LUDINGTON well put down by J. S. Stearns, with samples, is as follows:

Pleistocene.	Sand	198	198	10 inch casing to 204 feet.
	Pink clay	68	266	Water at about 300 feet, T. 53°
	Gravel	94	360	Both pink clays are calcareous.
	Pink clay	155	515	
	Gravel	61	576	8 inch casing to rock.
	Limestone	74	650	With 15 feet of porous granular limestone and salt water 35 feet below the casing.
Coldwater.	Blue shale	550	1200	
Antrim	Black shale.	200	1400	
Traverse Group		625	2025	Brown limestone 25; blue shale 35; brown limestone, oily, with H_2S 40; pure limestone 250, possibly Dundee?; brown sandy dolomite 160; calcareous shale 90.
Monroe Group?		279	2304	Dolomite 25; limestone 25, cf. Anderdon or Dundee; dolomite 25; Sylvania sandstone? 100; sandy dolomite and anhydrite 121; salt 8.

These sandy beds in the Monroe may be compared with those at 750 feet at South Bend; 1,100 feet at Dowagiac; 1,650 at Kalamazoo.

U. S. Geological Survey Well No. 25. Six miles S. E. of MANCHESTER. Manchester Oil Co. C. A. Elliot, driller. Corresponds to the record by W. F. Cooper already, which he considers all in the Coldwater formation. 8-29-1904.

Coldwater.

Sample No.	Depth.	
1	174–200	Blue shale.
2	220	Blue shale.
3	240	Blue shale.
4	260	Blue shale.
5	280	Blue shale.
6	300	Blue shale.
7	327	Blue shale.

Berea.

8	329	Horizon of Berea? This red shale clay might represent a weathered surface, or some other zone of special oxidation. The banding upon it is quite distinct. Compare Bedford shales. Compare Hillsdale at 1030–1033, Osseo, 800, Adrian, 514.

Antrim.

9	341	Usual shale.
10	352	Black shale. This looks very much like the Ohio black shale, and would seem to indicate that the horizon of the Berea here is at 327–329
11	400	Bluish shale.
12	490	Blue shale.
13	540	Brown shale, like No. 10.
14	570	Same.
15	600	Same. Compare Hillsdale 1350, Osseo 1145–1214, Adrian 805, Madison Oil and Development Co. 665.

Traverse.

16	660	Gray shale; non-effervescent.
17	690	Gray shale; slightly effervescent.

The samples from 600 feet down might quite likely be Traverse, or they might be a gray streak in the Antrim. From 327 feet down to 600 feet, or thereabouts, should be Antrim.

The elevation may be about 830 A. T. Assuming it to be 11 miles from Britton, El. 705 where the base of the Antrim is 210 feet down (or 495 A. T.) and that in this well at 600 feet is the base of the Antrim (at 230 A. T.) we get a dip of 24 feet per mile to N. W. which is not far from what one might expect. Compare also the Madison Lt. & Gas Co. well near Adrian (777 A. T.) in which 430-700 will correspond to 327-600 here? The dip indicated would be to S. E. This is abnormal and would indicate that an anticlinal indicated in Fig. 1 of the Ann Arbor Folio continues farther N.

The Berea horizon being about 500 A. T. might approach the bedrock surface near Macon.

This is near, and possibly the same as the well of U. Arnold of which it is reported that it struck brine at about 1,000 feet, about two miles from Clinton Sec. 2, T. 4 S., R. 3 E.

LOG OF CHEBOYGAN, MICH., WELL FROM EXAMINATION OF SAMPLES OF DRILLINGS.

BY W. C. ALDEN.

PLEISTOCENE.

Depths		
0–150	ft.	Red clay, highly calcareous.
150–203	"	Sand and gravel.
203–205	"	Sand.
205–230	"	Sand, gravel and red clay.
230–245	"	Gravel.
245–250	"	Sand with some calcareous material.
250–255	"	Sand and gravel.
255–270	"	Gravel
270–290	"	Fine sand with calcareous material.
290–300	"	Fine sand with calcareous material.
300–334	"	Gravel.
334–352	"	Gravel, coarse.
352–354	"	Fine sand with calcareous material.
354–356	"	Ditto, coarser.
356–360	"	Ditto.
360–375	"	Ditto, fine.
375–380	"	Fine calcareous sandy clay.
		2nd box of samples. Cheboygan well.
265	"	Light to whitish dolomitic limestone.
265–278	"	Chips of dark grayish dolomite with some quartz sand grains.
300	"	Light colored limestone.
320	"	Grayish, dark, porous, earthy dolomitic limestone.
		MONROE beds (Upper Silurian, waterlime and Salina).
380–438	"	Fine chips of brownish-buff-gray dolomite with a little chert.
?1400	"	Salt (March 12, 1901).
1360?–1550	"	Fine grayish sand and dolomitic material with some white chert and bluish and reddish shaly material.
1550	"	Beginning of NIAGARA (Guelph).
1615	"	Fine quartz sand, slightly calcareous.
1625	"	Ditto, brownish.
1635	"	Ditto, brownish.
1652	"	Light grayish crystalline dolomite (Cheboygan test well).
1725	"	Ditto.
1975	"	Buff fine angular grains of quartz, chert with some dolomitic material.
2000	"	Dark gray, very cherty dolomitic material.
2050	"	Fine, angular, gray dolomitic material.
2100	"	Ditto. LOCKPORT about here—2065.
2150	"	Ditto. ROCHESTER shale 2136–2200.
2175	"	Ditto.
2200	"	Ditto. Dark colored, nearly black.
		CLINTON.
2225	"	Ditto. Lighter colored.
2250	"	Ditto. Lighter colored. Contains small particles of iron or magnetite.
		MEDINA.
2300–2425	"	Dark purplish ferruginous material, reddish streak, in small flattened, rounded lenticular pellets. With this is some bluish shaly material, moderately calcareous. Some particles rounded. Also few quartz grains. Bluish shaly material increases in lower samples.
		LORRAINE. Lower part.
2300–2425	"	Dark drab shale, or dolomite, somewhat calcareous. Small particles of iron or magnetite.
2700	"	Ditto.
2725	"	Ditto.
		UTICA.

MORTON SALT COMPANY WELL, ECORSE.

Record begins with the bed rock and the depths of samples are numbered therefrom. To find the depth from surface add 62 feet to the sample number.

Pleistocene.		
Muck, thin clay. Surface deposits	62	62
SILURIAN.		
Monroe above Sylvania.'		
Light buff dolomites at 10 feet, perhaps oölitic	75	137
At 20 to 30 feet rather brisk effervescence, generally moderate to slow, some rounded sand grains.		
Samples 35, 40, 45, 50, 55, 60, 65, 70, 75 feet, light buff with moderate effervescence with acid. Occasional sand grains in 35, 40, 45. Sulphur in 60 and 65.		
Dolomites	60	137
Dark brown, bituminous, with sulphur and sometimes pyrites, with moderate effervescence.		
S. 80, 85, 90, 95, 100, 105 and 110 not quite so dark; 115 brown; 120, lighter. Compare Church No. 5 down to 290.		
Sylvania	65	262
Quartz sand, clear, very fine, most of the grains from .5 to .2 mm., rounded down to somewhere between .1 and .25 mm.		
S. 135, 140, 145, 150, 155, 160 very fine, 165, 170, from 175 on fine, 180, 185, 190, 195. Compare Ford 23, 235–325; Mt. Clemens, 965.		
Dolomite	20	282
Light, effervescence moderate, in specks (due to crystals perhaps) faster.		
S. 200, 205, 210, 215. Compare Ford 23, 325–340.		
Silicious dolomite	35	317
Dark brown, with red, rusty quartz sand and pyrites in spots, and very cherty at the base.		
S. 220 and 225 (with red, rusty quartz sand). From 225 to 245 are dark brown, with brisk to moderate effervescence. S. 240 and 245 have rusted pyrite and grains of quartz sand. S. 250 has a lot of chert and quartz. Compare Ford No. 23, 375–435.		
White sand like that above	35	352
S. 255, 260, 265, 270, 275, 280, 285.		
Sandy dolomite	10	362
Grains rounded down to .16 mm.		
S. 290, 295, dark, with .16 mm. rounded quartz grains which may have dropped in from above.		
Monroe below Sylvania?		362
Cherty dolomite	50	412
S. 300, much chert like Edison, Fort Wayne, well at 625 feet; 305, 310, 315 (drab color). At 320, 325, 330, 335, largely chert; at 340 to 345 almost solid chert, not effervescent. Compare Ford No. 23 at 440, and Church No. 5 at 420–520		
Dolomite	20	432
Dove colored, with relatively little chert.		
S. 350, 355, 360, 365. Compare Ford No. 23, 445, 450, 455, 460, 465.		
Dolomite	30	462
Bluish, buff, massive.		
Coarse chips at 375–385; S. 370, 375, 380, 385, 390, 395. Compare Edison 462–477.		
Brown dolomite	15	477
S. 400, 405, 410.		
Light dolomite	15	492
S. 415, 420, under microscope rounded brown grains.		
Dark dolomite	40	527
S. 425, 430, oölitic; 435, 440 with pyrite; 445, 450, 455, dark, bituminous, possibly oölitic; 460 quite dark and rusty; 465 lighter, sharp pieces, oölitic signs?; 470, 475, 480. Note that Ford No. 23 is oölitic at 465–470.		

Light dolomite 25 552

Stylolitic with black specks. Compare Ford No. 23, 505–510, 545, 550.

S. 485, 490 are sugary but not oölitic, but the latter have grains of gypsum.

Beginning of Salina?

Impure gypsum 45 597

Bluish, with some dolomite, and nearly pure at 525 feet.

S. 495 stuck together; u. m. largely gypsum; 500 to 505 some gypsum; 510 bluish gypsum, with part limestone, briskly effervescing; 515 and 520, blue with white gypsum; 525 largely solid white gypsum; 530 brown and white gypsum and dolomite. Compare Ford No. 23, 590–640, Edison Fort Wayne, 900–950, especially 925 with 525, this well running about 400 feet less (–62 ft. drift) than the Fort Wayne; about 100 feet less than the Ford No. 2 . Compare Church No. 5 at 720.

S. 535, 540 oölitic with dark, oval bodies, 445, 450.

Anhydrite is quite abundant at 565 + 62 ft.

S. 555, darker, bluer, slow effervescence with gypsum; at 560 gypsum streaks; 565 mainly anhydrite. Compare Edison Fort Wayne 1000 ft, Ford No. 23, 615–640. S. 570, 575 mixed; 580 cleaner buff dolomite; 585 u. m. mainly dolomite, bluish; 590, 595 mixed and bluish gray.

Dolomite 20 617

(Oölitic at 602 ft.)

Bluish dolomite and anhydrite 175 792

600, 605, 610, 615, 620, 625, 630, 635, 640, 645, 650, 655, 660, all bluish, coarse chips, with occasional faint specks of anhydrite; 665, 670 similar, thinner brown calcilutites; 670, 675, 680 similar; 685 u. m. almost wholly dolomite; 690, 695 and 700 the same; 705, 710, 715, lighter, with crusts of anhydrite and gypsum; 720 dolomite with no anhydrite; 725 stuck together, salty.

At 730 ft. is the first salt. Compare 795 at Ford No. 23. The Edison Fort Wayne well seems to have salt at higher levels, the first salt there at 1010 feet belonging to the upper part of this group, apparently.

Compare Church No. 5 at	890ft.
Eureka Wyandotte	730–800
Ford No. 23	795
Ford No. 22	819
Ford No. 21	820
Ford No. 7	792
Ford No. 1	830
Ford No. 4	783
Solvay No. 11 and 12	865
Solvay No. 13	880
Solvay No. 14	875
Solvay No. 15	865
Solvay No. 16	890
Romulus (Laurence & Griffeth)	925
Tecumseh Salt Co	828
River Rouge Improvement Co	815
Brownlee	875
River Rouge Salt Co	871
Saliotte & Ferguson	855
Penn Salt Co	830
Detroit Salt Co	906
Stroh	1150
Royal Oak	1543
New Baltimore	1600
Saint Clair	1600
Marine City	1604
Port Huron	1500

Salt	50	842
S. 730 bluish, like rock above; 730–775 brown salt. This is the bed most likely to contain potash. S. 730, 735, 740, 745, 750, 755, 760, 765, 770, 775.		
Dolomite	80	922
Hard. S. 780, 785, 790, 795, 800, slow effervescence, u. m. very little anhydrite, more just above the salt; S. 805, 810, 815, 820, blue and buff. Compare Ford No. 23, 922–927. S. 825, 830, 835, 840, 845, 850, 855, clear, buff, bluer at the bottom, very little anhydrite. Compare Wyandotte 870–900. Ford No. 23, 937–1000.		
Dolomite with anhydrite	10	932
S. 860 u. m. much anhydrite; 865 anhydrite and dolomite.		
Anhydrite with salt	10	942
S. 870, 875. While this is the second salt in this well, and would thus correspond to 940 ft. at Wyandotte Eureka, and 852 at Ford No. 23 (probably really to 1027) it is probable that these salt beds are not persistent. Edison Fort Wayne 1280–1292 may also correspond. Ford No. 1 is the same.		
Dolomite	5	947
This is merely a parting, but seems fairly persistent. Compare Ford No. 1, 968–976; Wyandotte 960.		
Salt	15	962
S. 885 light gray, 890 white, 895 impure gray salt. Compare Ford No. 23, 1022–1046.		
Dolomite, anhydrite and clay	100	1062
900 bluish and dark buff; 905 stuck together, salty, gray, and the rest of the samples to 995 are more or less stuck together; the effervescence moderate to slow; a little anhydrite generally visible under the microscope; the color, 910 gray and pink; 915 bluish and gray; 920 and 925 reddish and blue, salty; 930 not quite so red; 935 the same; 940 bluish, thin bedded, shaly; 945 the same; 950 quite muddy; 955, 960, 965 bluish; 970 blue, shaly; and 975, 980, 985, 990, 995, all similar, but the shaly stuff may have washed in from above. However, the coarser fragments are a bedded lime mud rock (dolomilutite). These correspond to the "slate" shaly beds in Ford No. 23, from 1046–1124. Compare also Wyandotte 970–1045; Church No. 6, 960–1160.		
Almost solid anhydrite	5	1067
S. 1000 solid anhydrite, lighter in color and less shaly looking. Compare: Edison Ft. Wayne . . . . . 1400 ft. Wyandotte . . . . . 1045 Ford No. 23.		
Dolomite and anhydrite	50	1117
S. 1005 u. m. dolomite and anhydrite, buff; S. 1010 bluish, salty; 1015 like 995; 1020 buff; 1030 rather buff; 1035 a shade bluer; 1040 and 1045 some anhydrite is scattered in large grains in dolomite. The base of this is the top of the main and it seems to me the most persistent salt bed. We should then compare: ? Church No. 6, Trenton . . . . . 1280 Wyandotte Eureka . . . . . 1080–1235 (less 45?) Morton . . . . . 1119–1323 Romulus . . . . . 1475–1600 with partings. Milan . . . . . 1540–1545 Zug Island . . . . . 1290–1528 Solvay No. 11 . . . . . 1370–1602 with parting. Edison Ft. Wayne . . . . . 1445–1636 Stroh . . . . . 1565–1815 Royal Oak . . . . . 2115–2475 Port Huron 1991–2190		
Salt, dolomite and anhydrite mixed	5	1122
Salt. Samples to 1075 +62	201	1323

Record of water well at schoolhouse in school district No. 3, CLAYTON TOWNSHIP, Arenac county. Goff Paul, Driller.

Clay	8 ft.	8 ft.
Sandy clay and stones	2 " 6 in.	10 " 6 in.
Very hard clay, color light blue	40 "	50 " 6 "
Quick sand and stones	130 "	180 " 6 "
Soft white clay	30 "	210 " 6 "
Sand and gravel	40 "	250 " 6 "
Hard pan	10 "	260 " 6 "
Loose water sand	5 "	265 " 6 "
Light colored blue clay	20 "	285 " 6 "
Hard pan	3 "	288 " 6 "
Hard rock (bed rock)	2 "	290 " 6 "
Blue slate	20 "	310 " 6 "
Hard rock (looks like limestone)	8 " 2 in.	318 " 8 "
Very dark blue slate	15 " 9 "	334 " 5 "
Sand stone	5 "	339 " 5 "

Record of test hole on Sam Rosenthal's farm in Mason township, Arenac county, one mile west of TURNER village, Turner township.

Black muck	2 ft.	2 ft.
Stones and sand	1 "	3 "
Yellow clay	11 "	14 "
Stones and hard pan	1 " 2 in.	15 " 2 in
Blue clay	4 "	19 " 2 "
Limestone, hard rock	2 "	21 " 2 "
Shale	8 "	29 " 2 "
Blue colored hard rock	1 "	30 " 2 "
Shale	7 "	37 " 2 "
Gray limestone	3 "	40 " 2 "
Shale	3 "	43 " 2 "
Gray limestone	2 "	45 " 2 "
Shale	2 "	47 " 2 "
Light colored hard rock	3 "	50 " 2 "
Alabaster, very white	21 " 4 in.	71 " 6 "
Blue slate	2 "	73 " 6 "

August 29, 1905. Goff Paul, Driller.

PORT ROWAN WELL, CANADA.

Quaternary.			
Surface clay to			338
Dundee (Corniferous)		212	550
Gray; fierce effervescence	338–363		
Grayish blue; fierce effervescence	363–413		
Grayish blue, brisk effervescence	413–440		
Dark brown; brisk effervescence	440–450		
Gray brown; brisk effervescence	450–455		
Gray blue or brown; brisk effervescence	455–470		
Bluish gray; brisk effervescence	470–510		
White, fine grained; brisk effervescence	510–515		
Bluish gray; brisk effervescence	515–564		
Middle Monroe		43	593
(From 550 to 554 slow effervescence)			
Lucas? then Amherstburg, Anderdon and Sylvania?			
"Corniferous or Oriskany"			
White, granular; brisk effervescence	564–569		
"Corniferous"			
Blue limestone; brisk effervescence	575–580		
"Corniferous or Oriskany"			
White, granular; brisk effervescence	575–585		

Lower Monroe and Salina?		267	860
Gray dolomite; slow effervescence	? 593		
Dark blue with gypsum and shale; weak effervescence	593–745		
Grayish dolomite; weak effervescence	755–770		
Dark blue dolomite; weak effervescence	790–805		
Gray dolomite; weak effervescence	805–825		
Gray dolomite; weak effervescence	845–860		
Salina?		360	1020
Grayish blue anhydrite; weak effervescence	860–875		
Blue anhydrite; weak effervescence	875–920		
Blue anhydrite; moderate effervescence	920–945		
Gray blue; moderate effervescence	945–960		
Gray, fine grain; moderate effervescence	960–975		
Blue; moderate effervescence	975–995		
Gray blue; moderate effervescence	995–1020		
Niagara—Guelph and Lockport		200	1220
White sugary Guelph; weak effervescence	1020–1060		
Dark; weak effervescence	1060–1090		
Rochester shale		25	1245
Dark blue; weak effervescence	1220–1245		
Clinton Dolomite		75	1320
White sugary; weak effervescence	1300–1305		
Yellow; weak effervescence	1305–1310		
Drab, argillaceous	1310–1315		
Light gray	1315–1320		
Medina Sandstone		140	1460+
Red	1320		
Blue shale	1335–1370		
Blue	1375–1380		
Blue (slightly calcareous)	1380–1385		
Green (light)	1412–1414		
Red	1414–1460		

ROMULUS.

Six miles N. E. of Ecorse, drilled April 6-June 25, 1903, on place of Emil Twark by Newell for Laurence and Griffeth, on the S. E. ¼ of the N. W. ¼ of Sec. 12. 620 A. T.

Drift		92
Gravel		95
Lime		116
Gray li	25	141
Marcellus.		
Coal[1]	2	143
Black slate	7	150
White lime	7	157
Black slate	15	172
Black shale	10	182
Dundee.		
Lime	63	245
Black shale	5	250
Lime	36	286
Black lime	12	298
Upper Monroe.		
Gray lime	24	322
White lime	63	385

[1]This is the driller's record—no samples were saved from this hole.

Sylvania?

	White sand	5	390
	Black slate	8	398
	White sand	65	463
	Sand rock	22	485
	White lime	15	500
	Sand rock	45	545

Lower Monroe?

	White lime	240	785
	Blue lime	10	795
	White lime	75	870
	Brown shale	12	882
	White lime	43	925

Salina.

1	Salt rock	35	960
	White lime	25	985
	Brown shale	15	1000
2	Salt rock	46	1046
	Slate	7	1053
3	Salt rock	34	1087
	White lime	30	1117
4	Salt rock	25	1142
	White lime	32	1174
5	Fine white salt	24	1198
	Lime	7	1205
6	Salt rock	53	1258
	Lime	5	1263
	White lime	7	1270
7	Salt	20	1290
	Lime	25	1315
	Shells and slate	62	1372
	Lime	26	1398
	Salt rock	27	1423
	Shells and slate	30	1453
	White lime	23	1476
8	Salt rock	45	1521
	Slate	20	1541
9	Salt rock	27	1568
	White lime	15	1583
10	Salt rock	20	1603
	Lime	20	1820

SAGINAW PLATE GLASS COMPANY.

This concern has put down 7 wells at the south end of W. Saginaw. The elevations vary but slightly being about 600 A. T. They lie near the S. E. cor. of sec. 33, T. 12 N., R. 4 W. The following is a record from samples, mainly from No. 4, with references to corresponding horizons in other wells.

Pleistocene.

Fine sand, Algonquin beach (½ m m.)	5	5
Plastic red clay	20	25
Like that at Paines, lacustrine, calcareous.		
Clay, blue	53	78
Bottom 6 feet "putty." All calcareous.		
Gravel with water	2	80
Till "hardpan" with coal	21	101

8 in. casing { 106 ft. in No. 1. / 111 ft. in No. 2. / 122 ft. in No. 3. }

Saginaw Formation.		
Dark shale, Lower Verne coal horizon? "Bastard"	14	115
Light (fire clay) and dark shale	7	122
Blue shale	17	139
Black shale	15	154
Coal, large Saginaw seam? or Middle Rider. Water Sp. Gr. 1.000	6	161
White shale, with black impressions "Fire clay."	4	165
Dark shale. Saginaw coal horizon?	8	173
Blue shale with some hard seams	5	178
White and brittle blue shale (probably some sediment)	½	178½
Dark gray shale	19½	198
Very dark dirty shale	13	211
Coal horizon? Lower Rider? Water Sp. Gr. 1.005		
Dark shale	9	220
Gray shale	79	299
Water at 280 Sp. Gr. 1.005.		
Shale, part dark, part "fire clay" light	9	308
Lower coal horizon?		
Shales with nodules or bands of siderite	56	364
Very dark shale, coal horizon? Bangor Rider	12	376
Water at 375 Sp. Gr. 1.006.		
Blue shale	19	395
Micaceous sandstone	9	404
Very dark shale; almost coal	21	425
Near 410–425 coal horizon. Bangor coal?		
Dark shale	49	474
Water at 476 Sp. Gr. 1.016. Much gypsum.		
Parma Conglomerate and Sandstone.		
Transition sandstone, fine grained	22	498
Sand rock	23	521
Conglomeritic sandrock 59	14	535
Two samples missing, 535–583. I think they were Bayport limestone. Top beds at 476 contained some petroleum "gum" inspissated in a cavity. There was a ten-inch drop of the tools. The base samples are full of split white quartz pebbles. In No. 2 this stratum is said to come at 520–555. In No. 7 this stratum is said to come at 485.		
Compare at E. Saginaw 292.5–399; Litchfield, Carrollton, 302–411; Ketcham well 310–430; Gallegher 345–482; Sutherland 341–408.		
Bayport or Maxville Limestone.		
Top at		535? or 583
Limestone	81	616
Water at 561 ft. Sp. Gr. 1.012.		
Note that the water was fresher than at the top of the Parma. There was propably much erosion just above this, and the division between it and the Parma is irregular. In No. 2 it is from 555 to 625. Temperature 56° at 630 ft. by thermometer 9109, March 23, 1906.		
Michigan Series.		
Black and dark shale	35	651
Gypsum	25	676
Near margin of this basin at this time? Compare No. 2 gypsiferous shales to 717.		
Dolomite	12	688
Alma 696.		
Blue shale	58	746
With lime and gypsum at top, sandy 735–743.		
Alma 905–945.		
Water at 620 Sp. Gr. 1.024.		
Note the doubling of the salinity on striking the Michigan. Casing to keep out the gypsum goes to 698 feet. This second casing to cut off the gypsum somewhat over 600 feet deep is noticeable in all the wells.		
Gray limestone	5	751
Dark sandy shale	9	760
Gray limestone	14	774

Water at 775 ft. Sp. Gr. 1.120?; more salt, less gypsum.		
Blue limestone	21	795
Sandy shale	14	809
In No. 7 3 ft. of red shale at 785 ft.		
Dolomite	11	820
Base in No. 6 at 812 ft. In No. 7 at 822 ft. In No. 2 from 717 to 822 ft is dolomitic limestone.		
Upper Marshall (Napoleon) Sandstone.		
In No. 7 at 887, in No. 2 at 913. Water at 27° .5 has Sp. G_2. C. 1.193.	78	898
By salometer 83° to 94°.		
Lower Marshall.		
Red clay	2	900
5 ft. in No. 7 to 892; 3 ft. in No. 6, in No. 1 at 906 ft. In No. 3,500 ft. West there is said to be more lime in the salt rock.		

This is the well known base of the salt (this red shale) all through the district, the redness *may* be due to oxidation by the sulphates of the original brines, the sulphur being at the same time reduced to pyrite. the brines now are low in sulphates, but strong in ammonia. The following is the analysis of F. S. Kedzie:

$MgSO_4$	.7695	
$CaCl_2$	45.0245	
$MgCl_2$	17.2361	
$MgBr_2$	.3496	
NaCl	229.2549	
$FeCO_3$	.1537	(Sp. test .041 to .061 Fe)
NH_4Cl	.051	

Tests by E. D. Campbell give similar figures, except SO_4 as $CaSO_4$ is but .857, SiO_2 is .026, K. is 0.

No. 1 in 4-inch casing 26-inch stroke gave with 3½-inch valve 15 gallons a minute.

Or with 3½ inch cup valve, 20 inch stroke 18 gallons a minute. Or 162 barrels in 24 hours.

No. 3 with 25 strokes 3½ inch valve, 30 inch stroke yielded 16 gallons a minute, 144 barrels a day its limit. At first 3 pails (30 quarts; 7½ gallons) per minute was the limit; after dynamiting it rose to 16 gallons.

Fifteen years ago when all the salt wells along the river were running there was only 155 feet of salt water in the holes, and a 11-second well, i. e. one which filled a 10 quart pail in 11 seconds, i. e. 13.6 gallons a minute was a very good well, and a 15-second well (4 pails or 10 gallons a minute) a good well. Now (1906) the head has risen to 175 feet. If all pumping was stopped it would in time run over.

SUCKER CREEK WELL.

Log of Sucker Creek well, Anderdon Township, Essex county, Ontario. About 4 miles E. of Detroit river, E. & S. E. of Ballard's reef.

60	Surface soil blue clay and gravel. At 72 H_2S water to top of ground.
200	Slightly eff. dol. Angular fragments.
300	Same light buff.
400	Fiercely effervescent li., sandy looking. Coral reef? Anderdon?
410–440	White quartz sand. Sylvania.
600	Brown and buff. Not effervescent or slow.
635	Brown and blue, slow effervescent (667–683) 16–18 ft. of gypsum.
676	Brown and blue, slow effervescent. Fresh water cased off at 683 ft.
680	Brown and blue, thin, angular, effervescent.

720	Brown and blue, slow.
760	Brown, blue and white. I think gypsum, slow eff.
785	Brown, slow eff.
890	Slow or no eff.
1025	Slow or no eff. A good deal of blue shaly material.
	At 1075–1080 trace of salt sand with a little salt water; enough to drill with
1075–1125	Brown dolomite. At 1120 feet more water which rose 700 feet in hole and could be bailed down only to between 300–400 feet.

YPSILANTI.

On flat of Huron River, below town on Cremer farm, about 300 feet from Old Cornwall well near City Water Works, about 682 A. T.. Lat. 42° 14′.

A. H. Marsh, Contractor. Banner Oil & Gas Co., and Ypsilanti Development Co.

Letters A. H. Marsh, 11-17-'04, 3-1-'05, 4 to 10, '05.

Clippings: Grand Rapids Herald, Sept. 1, '04. Detroit Free Press, 8-30-'04, 11-16-'04. Michigan Investor, 3-26-'04. Detroit Journal, 10-8-'04, 10-25-'04. Cleveland Finance, 3-26-'04. Ypsilanti Press, 4-23-'04, 10-31-'04, 10-4-'05. Bellevue Enterprise, 11-9-'04. Detroit News Tribune, 11-20-'04. Detroit News, 10-31-'06.

In Geological Survey Office, samples at 700′, 1,150′, 1,200′.

Pleistocene.		
Drift	90	90
At base of gravel water flows with T. 51° 2. T. 49° 7 at 90 ft. by thermometer 9114. 10 ft. drive pipe to 91 ft. T. 51° 2 at 128 ft. by thermometer 3022 C. 45 minutes down.		
Devonian Antrim.		
"White shale"	51	141
"Some gas" at 135 ft.; bleached? A little water, no smell.		
Black shale	150	291
Traverse.		
Limestone shale	25	316
With a flow of gas. Hard shells at 300 ft. T. 53° 5 F.		
Brown shale	204	520
This Traverse is also reported as 50 limestone, then blue shale, then black shale, then limestone, then black shale, and the change to Dundee at 525 ft. At 520 ft. T. 57° 2 F.		
Dundee.		
Limestone	160	680
S. at 600 tests limestone with Sherzer. Mineral water at 525 ft., 530 ft. with gas H_2S, also at 570 ft.		
Monroe.		
Dolomite	80	760
S. at 700 ft. slow effervescing dolomite, at 680 ft. more water quite salty with some gas and traces of oil, e. g. at ("730") or 720 ft., at which point it was fruitlessly shot with nitroglycerine, Nov. 16, 1904.		
At 710 ft. T. 59.4° F	440	1200?

Sylvania.

White sandstone "375 ft. to 390 ft. of it at 1150 ft.

S. 1150 ft. typical Sylvania sandstone, white, Dec. 17, 1904.

S. water at 1175 feet.

S. 1200 brownish sandstone, Feb. 9, 1905, looks like the samples near the bottom of the Sylvania.

Well 1210 ft. deep. Ypsilanti Press, Oct. 4, 1905.

Has it been deepened?

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B.

Numerous lists of towns with wells will be found on pages 63, 66, 70, 72–75, 77.